Phy 310

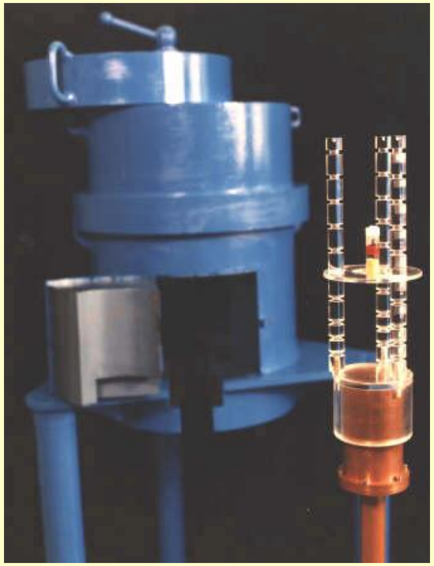
Detectors and Accelerators

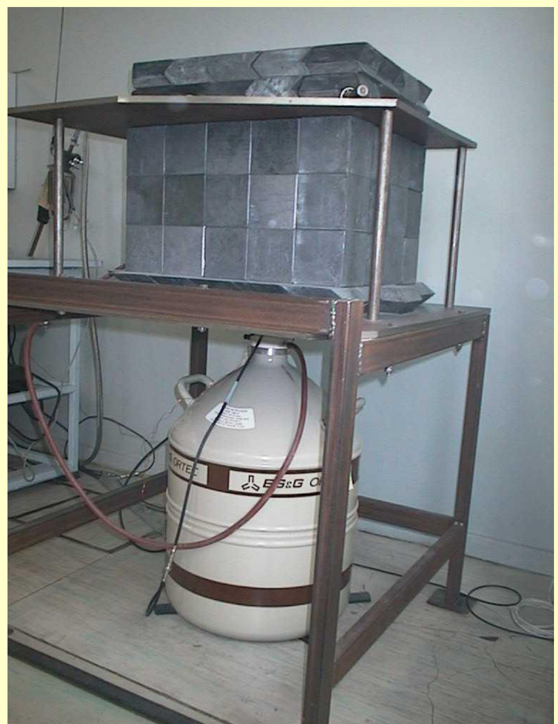
Dr. Mohamed Salem

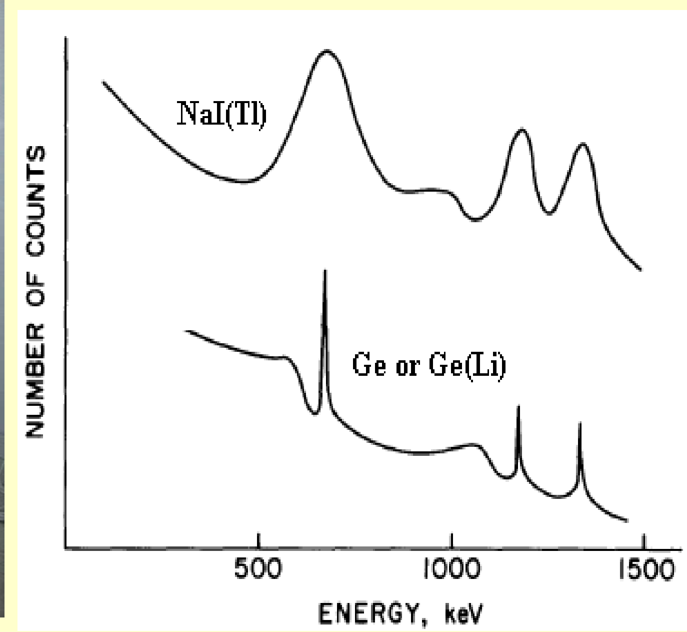
1- Detectors: General Properties of Radiation Detectors. Ionization Chambers. Proportional counters. Geiger Muller Counters. Scintillation Detectors , Radiation Spectroscopy with Scintillation. Semiconductor Diode Detector. Germanium Gamma Ray Detectors, Lithium-Drifted Silicon Detectors. Slow Neutron Detection Methods. Miscellaneous Detector Types.

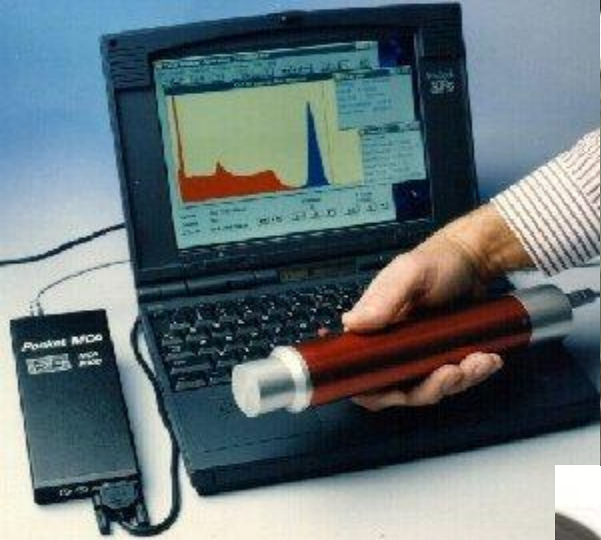
2- Accelerators: Ion Source. Electrostatic Accelerators. Cockcroft-Walton Accelerator, Van de Graaff accelerator, Tandem Van de Graaff Accelerator. Magnetic Resonance Accelerator. Cyclotron Accelerators, Synchrocyclotron Accelerators and Synchrotron Accelerators. Linear Accelerators. Colliding Beam Accelerators.

Some Applications



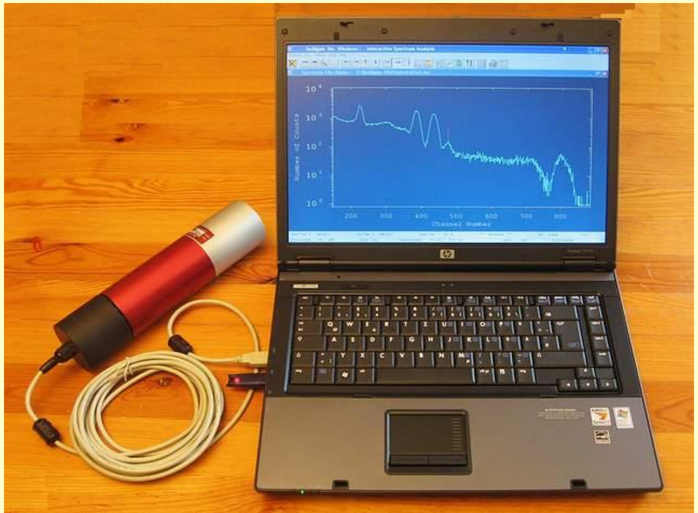





Pocket MCA

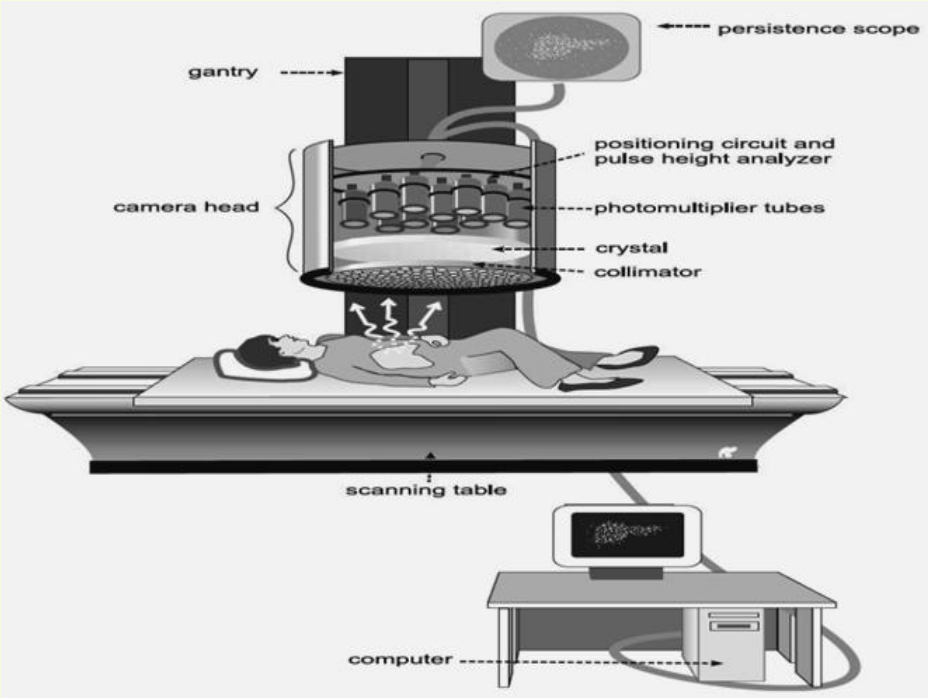

ORTEC
AMETEK
Trans-SPEC

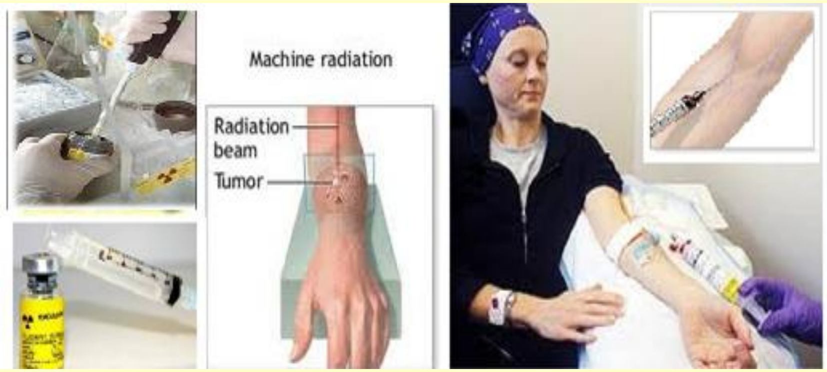


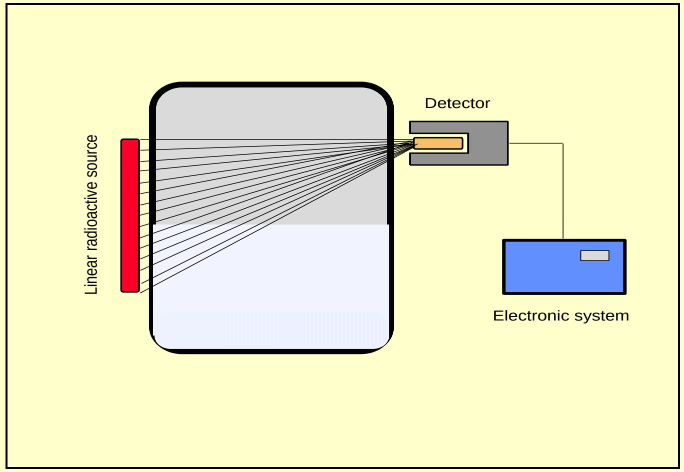



OSPREY

Gamma Camera







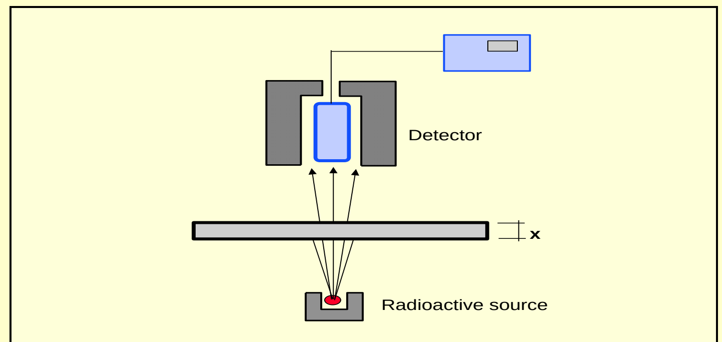
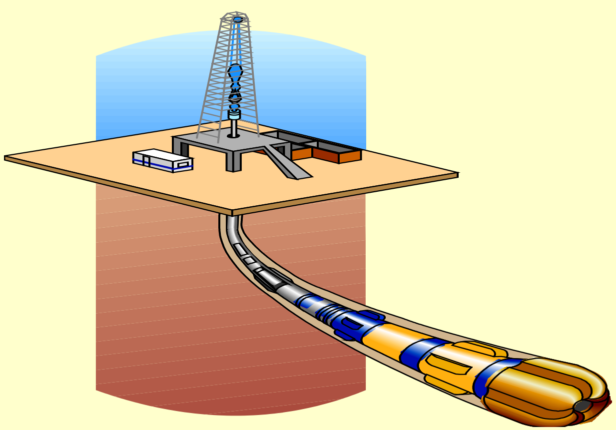
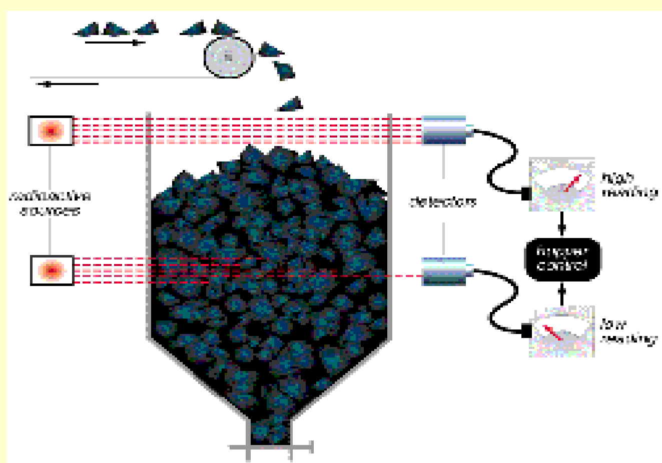
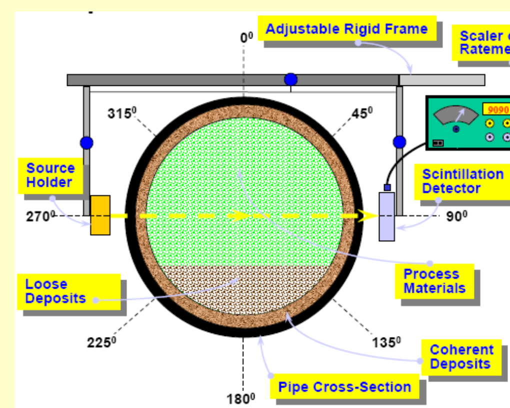
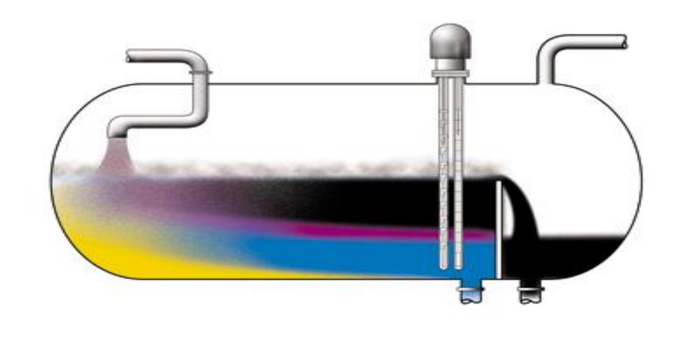


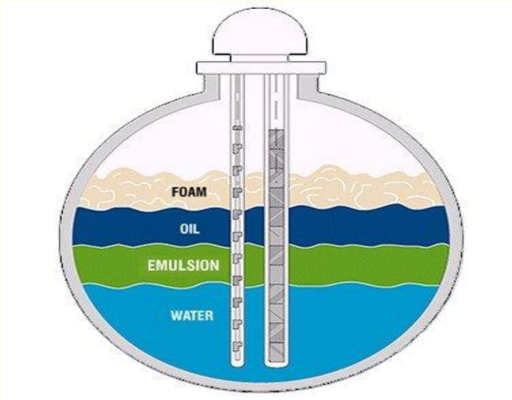
Figure 1.1: Transmission method

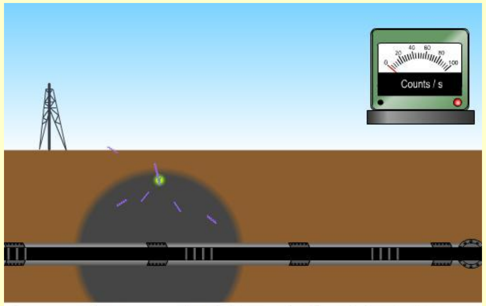




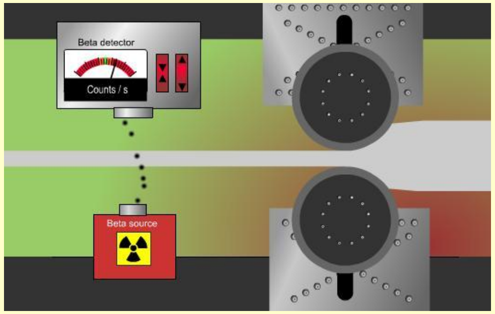








The gamma radiation can pass through the ground and be picked up by the gamma detector.



الجرعات الإشعاعية التي يتعرض لها الإنسان



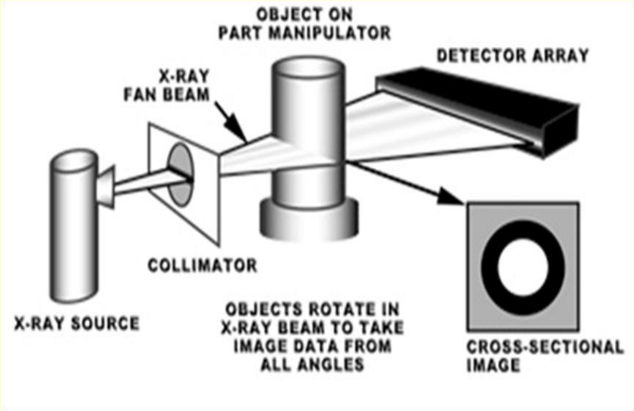

	أ – مصادر إشعاعية طبيعية	الجرعة الإشعاعية المكافئة مللي سيفرت/سنه
1	الأشعة الكونية والخلفية الإشعاعية عن سطح البحر	0.46
	ب – مصادر إشعاعية صناعية	
1	مشاهدة التلفاز الملون لمدة **3** ساعات	0.06
2	عدد **2** صورة أشعة سينية للصدر	0.16
3	عدد **2** صورة أشعة سينية للمعدة	4.88
4	عدد **2** صورة أشعة سينية للأسنان	0.08
5	عدد **2** صورة أشعة سينية للجمجمة	0.44

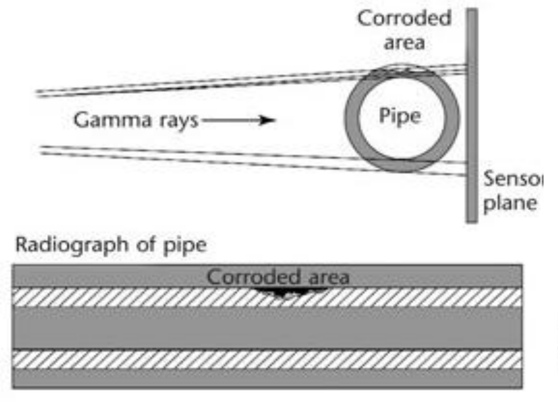


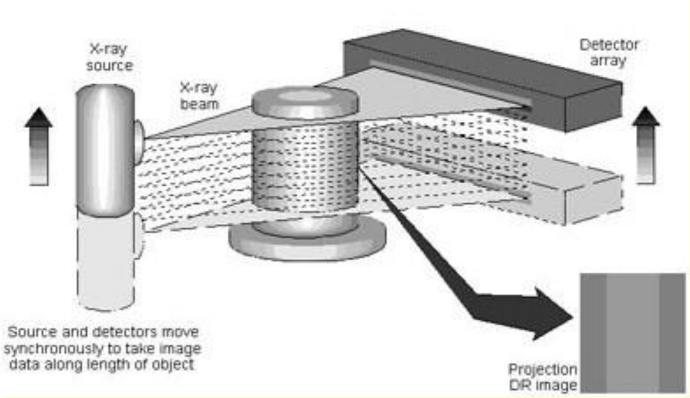


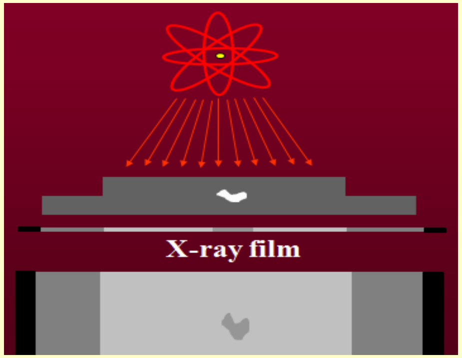
Film placed on vessel I.D.
for circumferential weld
inspection.

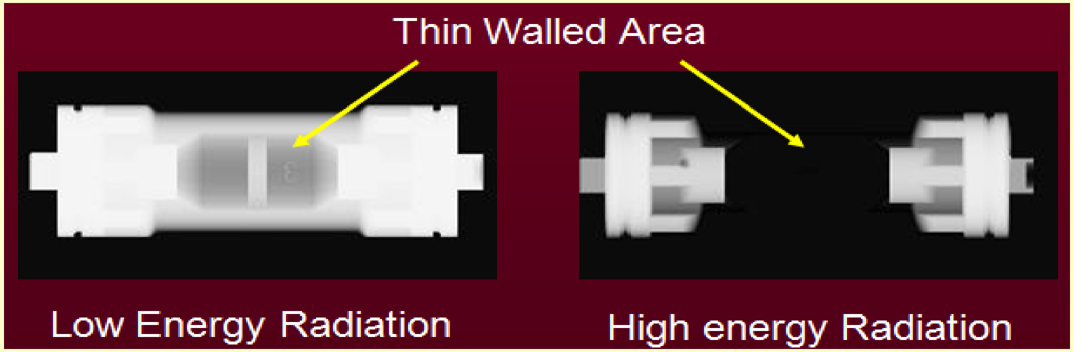

source point
film

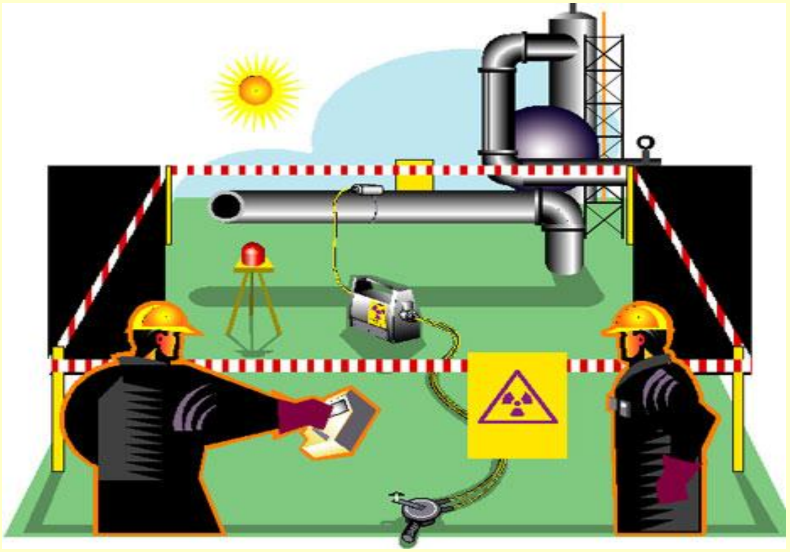

OBJECT ON
PART MANIPULATOR
DETECTOR ARRAY
X-RAY
FAN BEAM
COLLIMATOR
X-RAY SOURCE
OBJECTS ROTATE IN
X-RAY BEAM TO TAKE
IMAGE DATA FROM
ALL ANGLES
CROSS-SECTIONAL
IMAGE

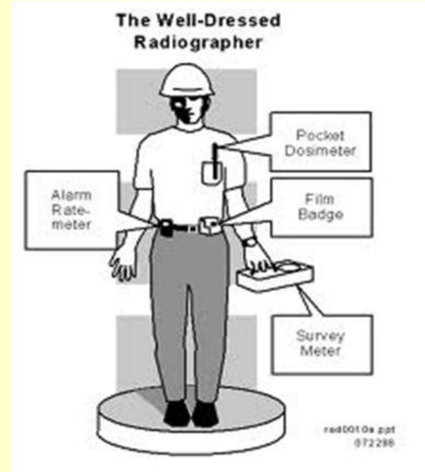

Corroded
area
Gamma rays
Pipe
Sensor
plane
Radiograph of pipe
Corroded area


X-ray
source
X-ray
beam
Detector
array
Source and detectors move
synchronously to take image
data along length of object
Projection
DR image


X-ray film


Thin Walled Area
Low Energy Radiation
High energy Radiation



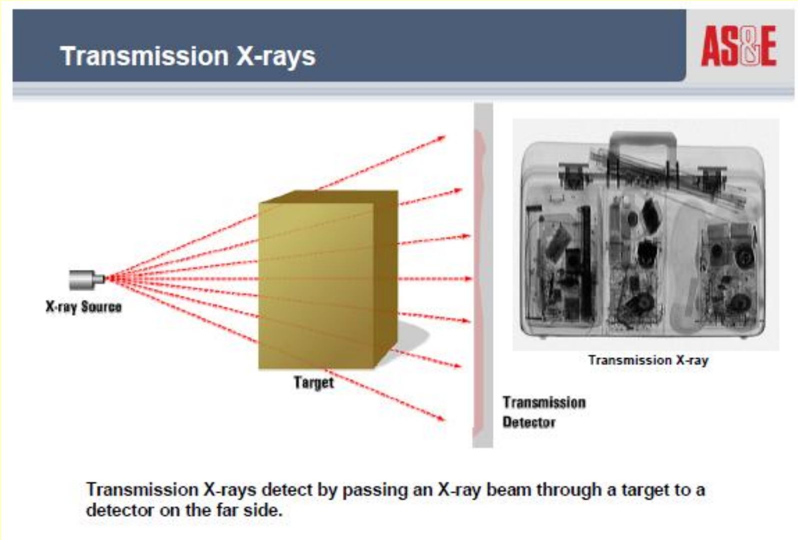


Survey Meter

Pocket Dosimeter

Radiation Alarm

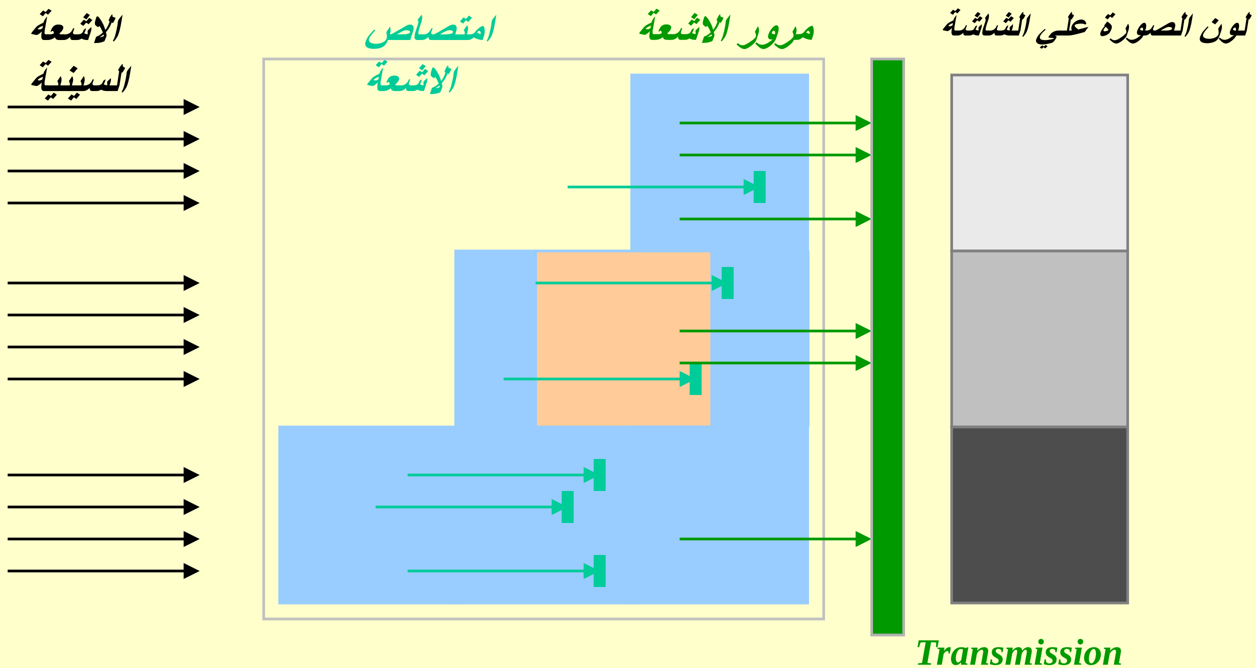
Radiation Badge



Transmission Imaging

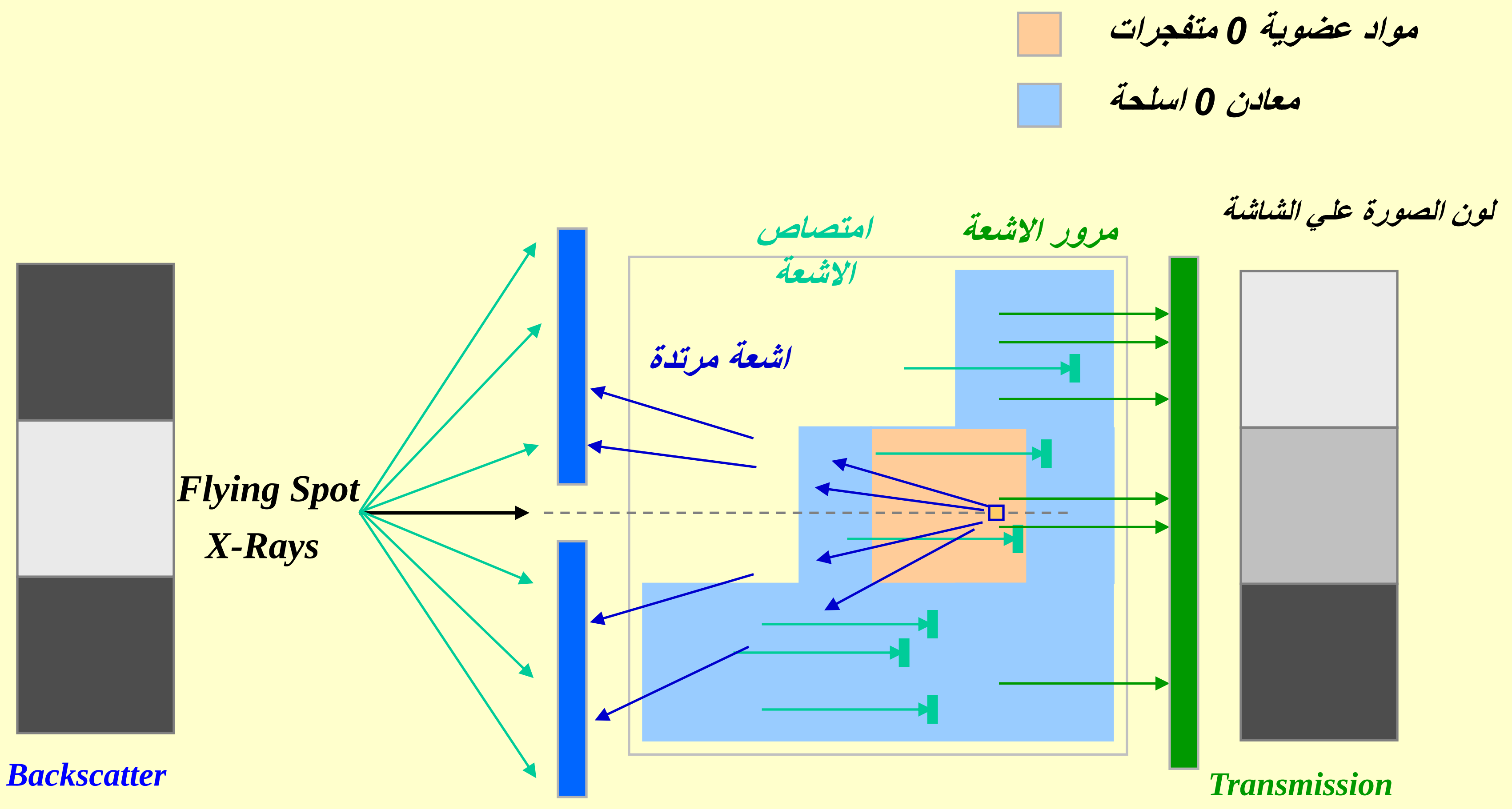
المواد العضوية المتفجرات

المواد المعدنية الاسلحة



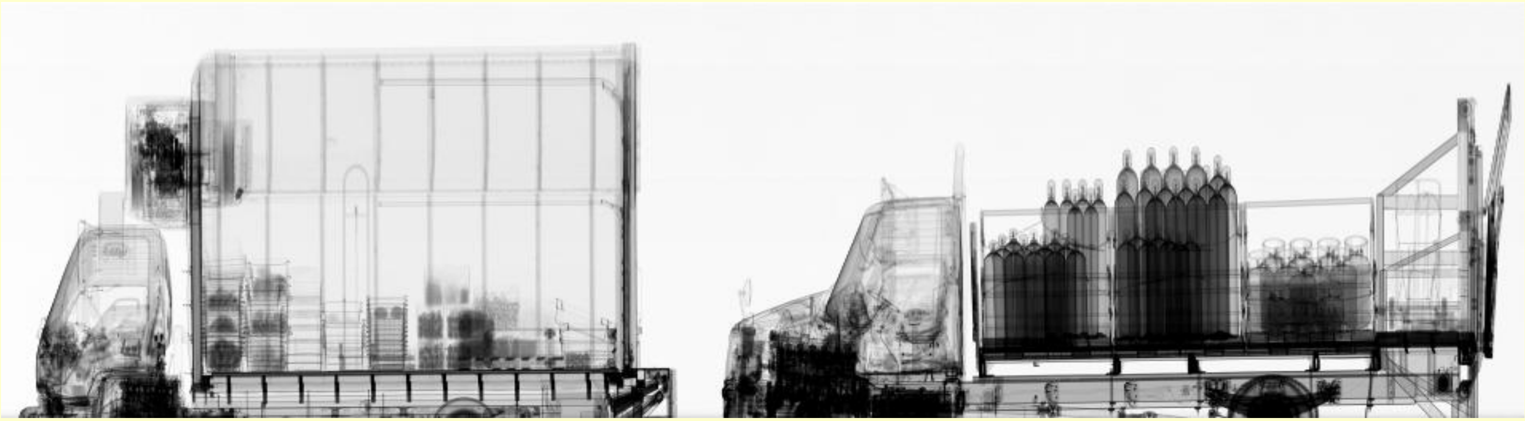
صور الكثافات المختلفة للأشعة النافذة

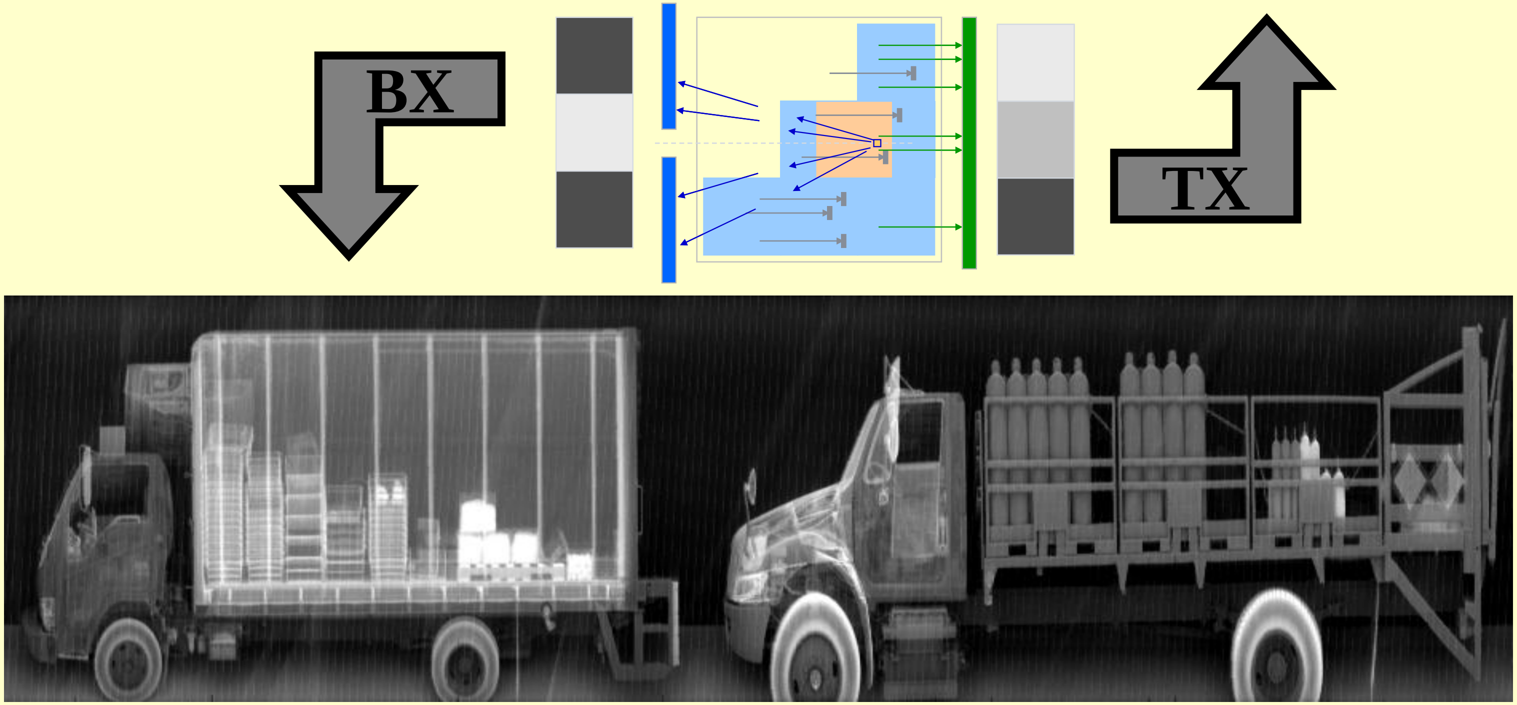
Backscatter Imaging

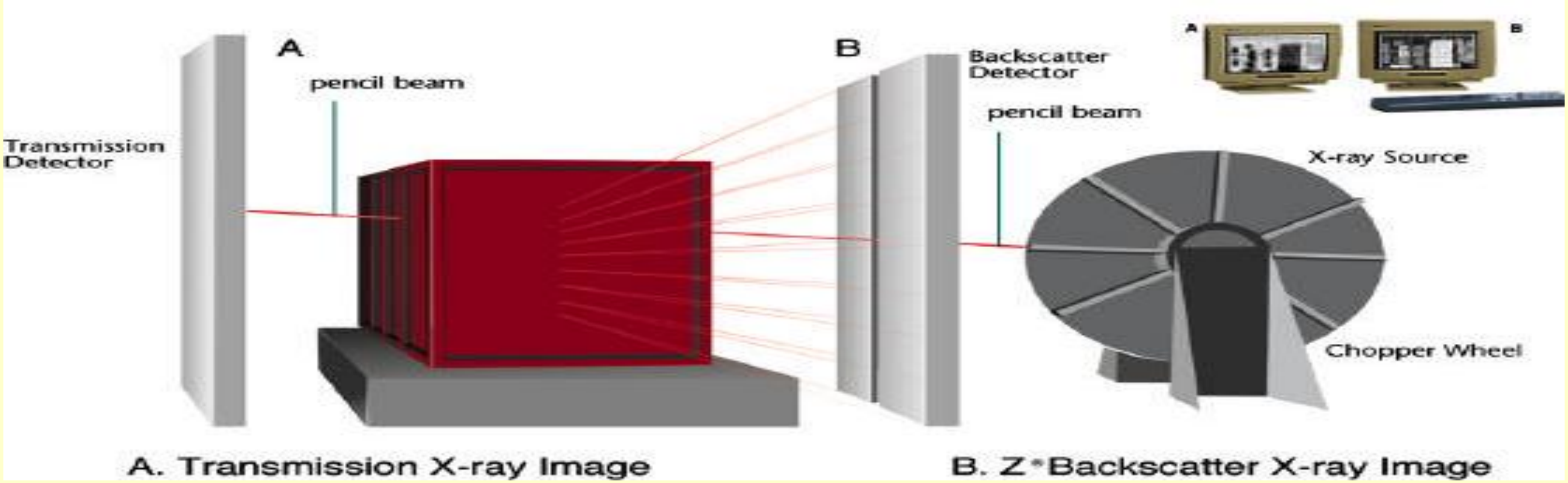


صور للمواد المختلفة للأشعة المرتدة

Transmission and Backscatter Images







الطاقة

من 50 الي 500 كيلو الكترون فولت

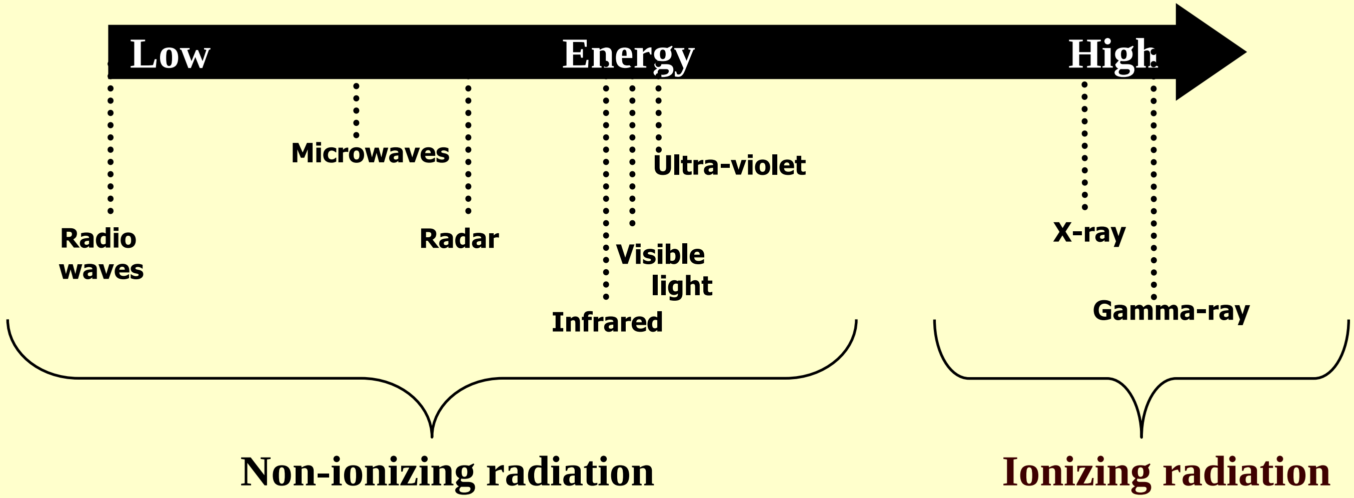
الطاقة

من 1 الي 9 مليون الكترون فولت

x-rays and gamma rays

Ionization radiation

Electromagnetic radiation



◙ Individual wave packets of this radiation are called **photon** ◙

◘ **The main difference between gamma and x-ray is their origin** ◘

While x-ray are produced by atomic excitation or from an electron as it changes direction when passing an atomic nucleus; this latter type of x-ray is called bermsstrahlung radiation, gamma rays are emitted by transition from excited states in the nucleus.

Applications of gamma rays spectroscopy

In radiation physics, measuring and studying the energy gamma spectra emitted from radioisotopes are very important and have many applications.

1) **Identification of the radioactive isotopes.**

2) **Study of the nuclear structure.**

3) **Measuring the absorbed doses**

4) **Determination of the interaction cross section.**

¤ To get a spectrum with high accuracy we must have ¤

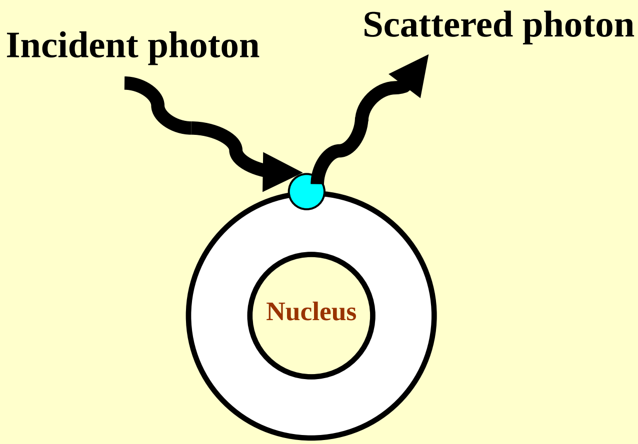
1) **Detection and recording system " method of measurements ".**

2) **Good values for detectors factors that concern the measurements analysis "efficiencies".**

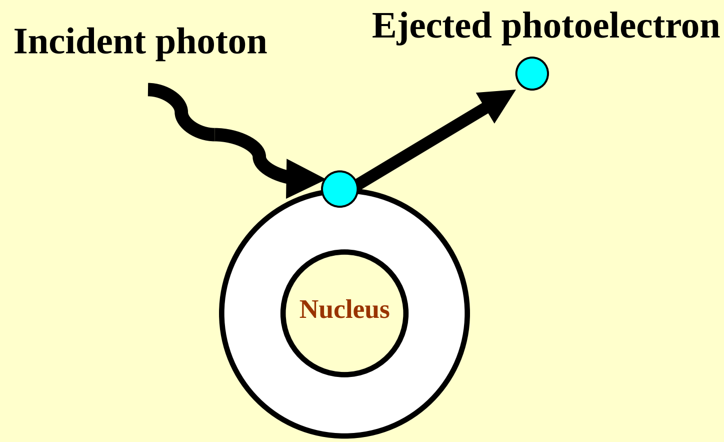
Interaction of photons with matter

■ The most important types of interaction ■

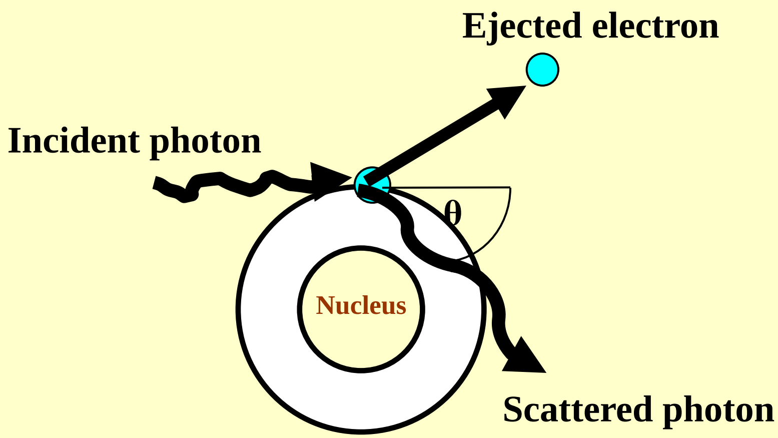
1) Rayleigh scattering (σ_{coh})



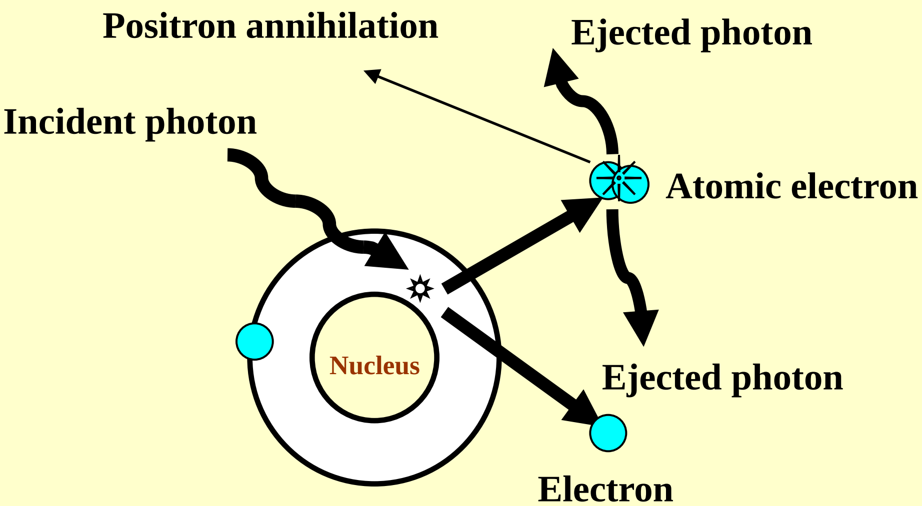
2) Photoelectric absorption (σ_{pe})



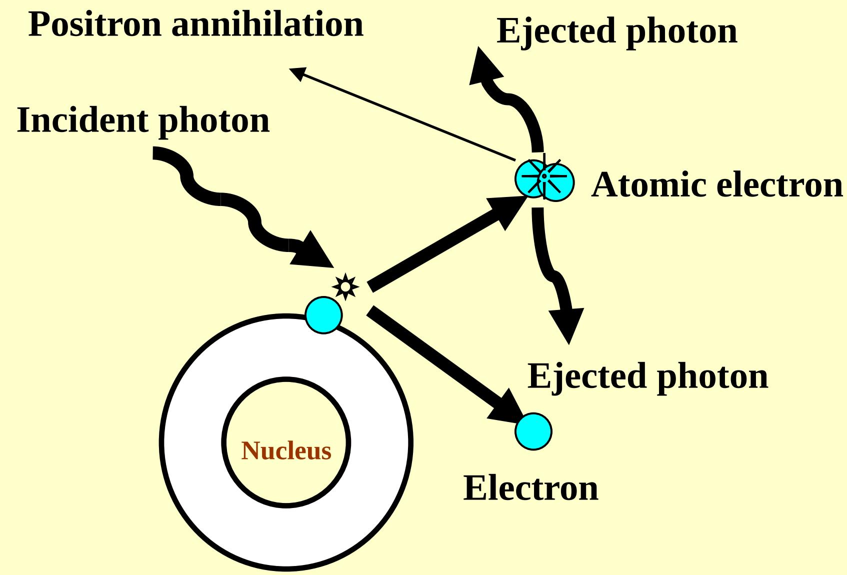
3) Compton scattering (σ_{incoh})



4) Pair production (σ_{pair})



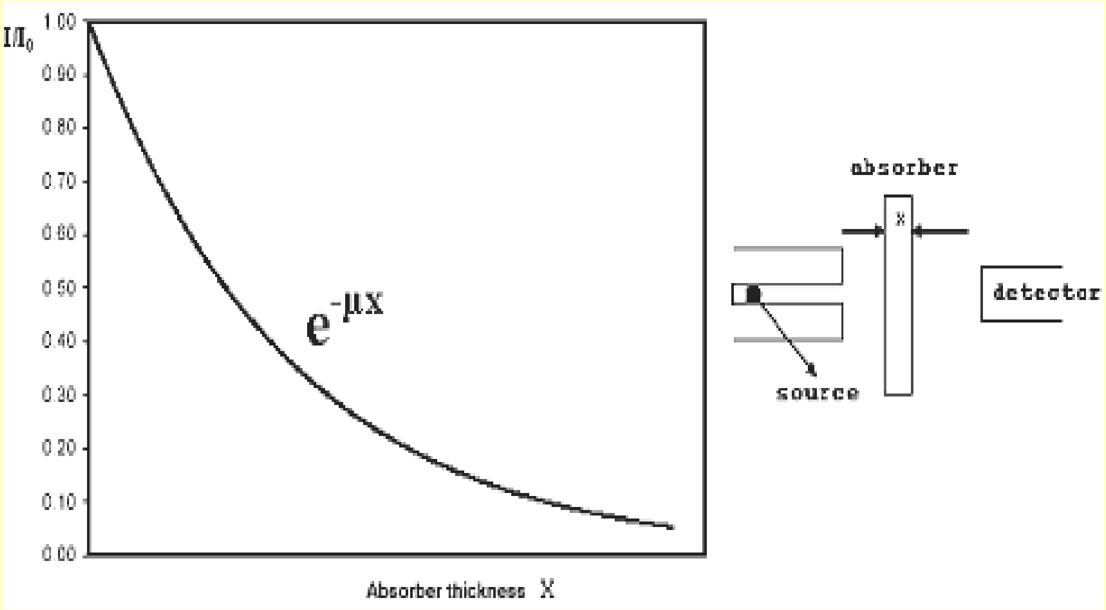
5) Triple production (σ_{triple})



The Total Attenuation Coefficients (μ)

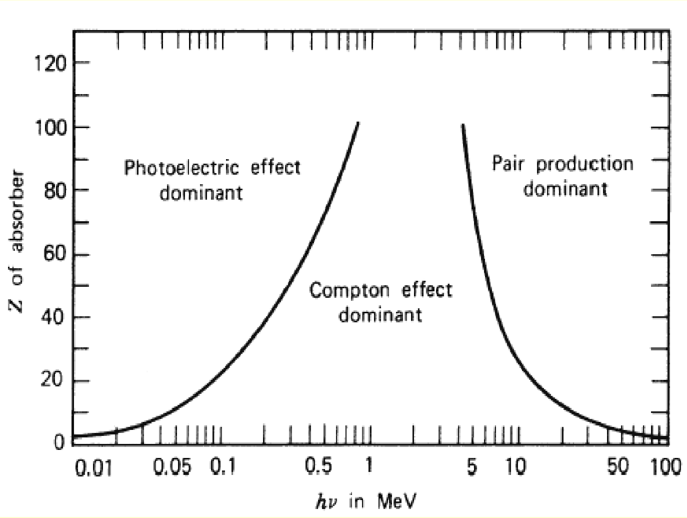
$$\mu = {}_{coh}\sigma + {}_{pe}\sigma + {}_{incoh}\sigma + {}_{pair}\sigma + {}_{triple}\sigma$$

Gamma-ray Attenuation

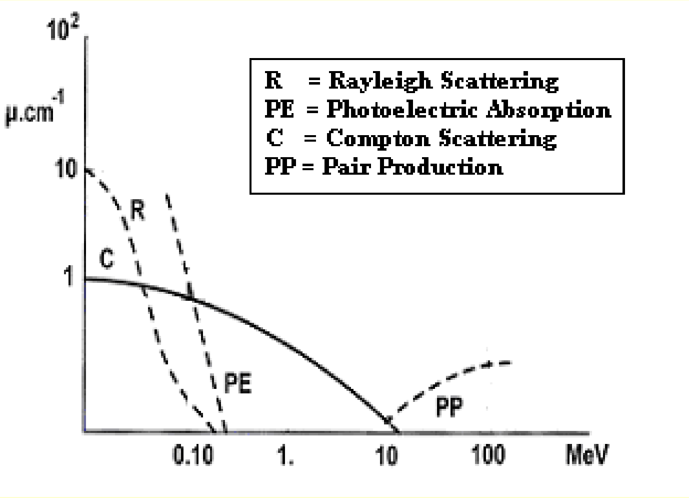


$$I = I_0 e^{-\mu x}$$

$$I = I_0 e^{-\left(\mu/\rho\right)\rho x}$$

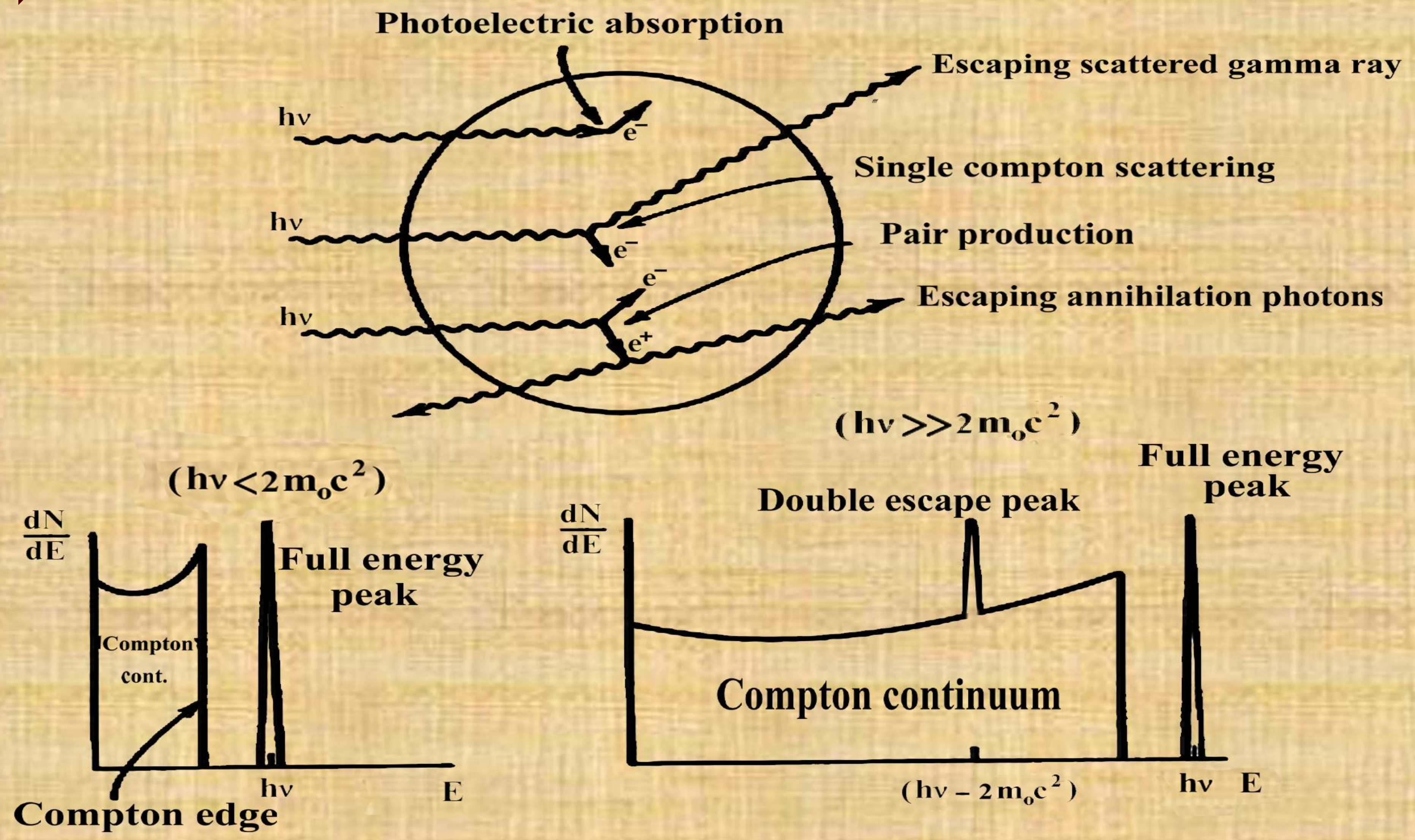


$$\frac{1}{\mu} = \lambda = \frac{\int_0^\infty x\, e^{-\mu x} dx}{\int_0^\infty e^{-\mu x} dx}$$

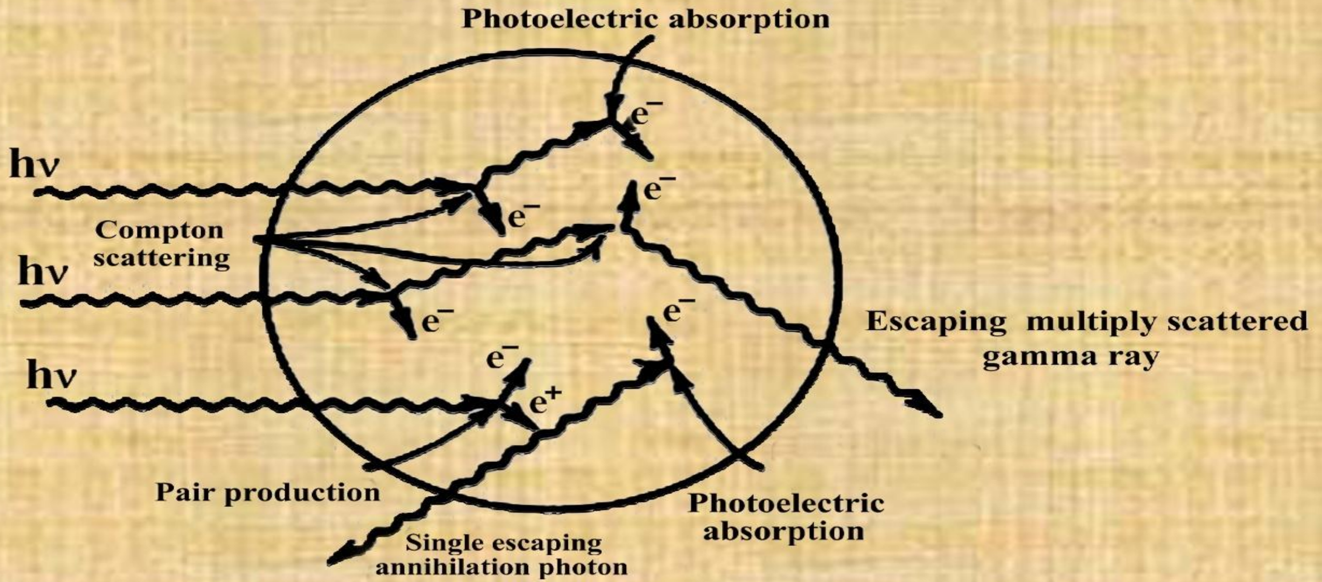


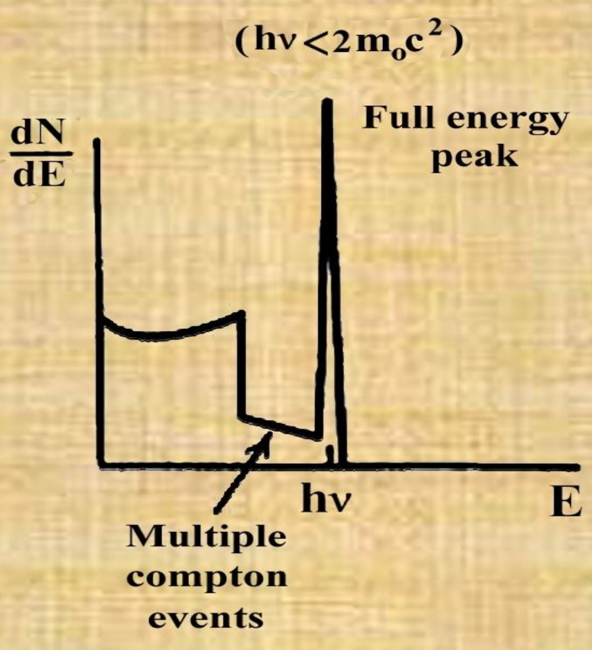
Energy deposition and spectrum for various detector sizes

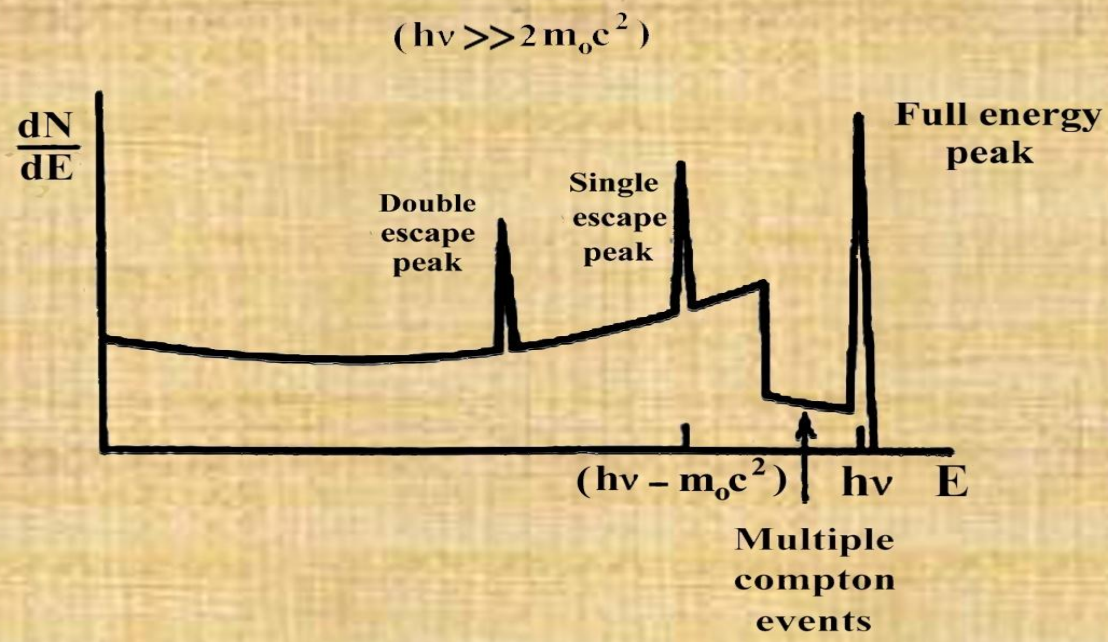
- **Small detectors**



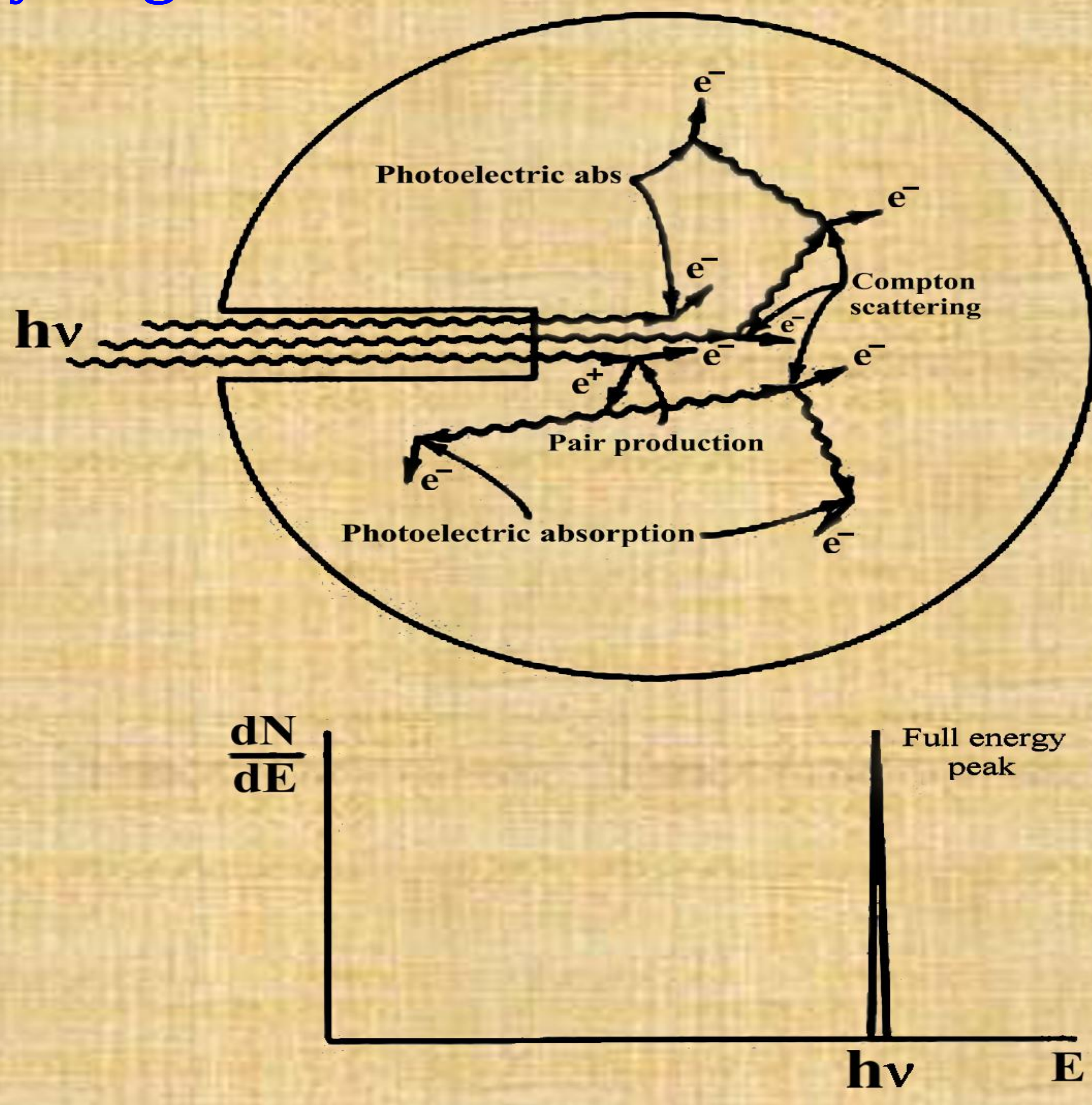
Intermediate size detectors



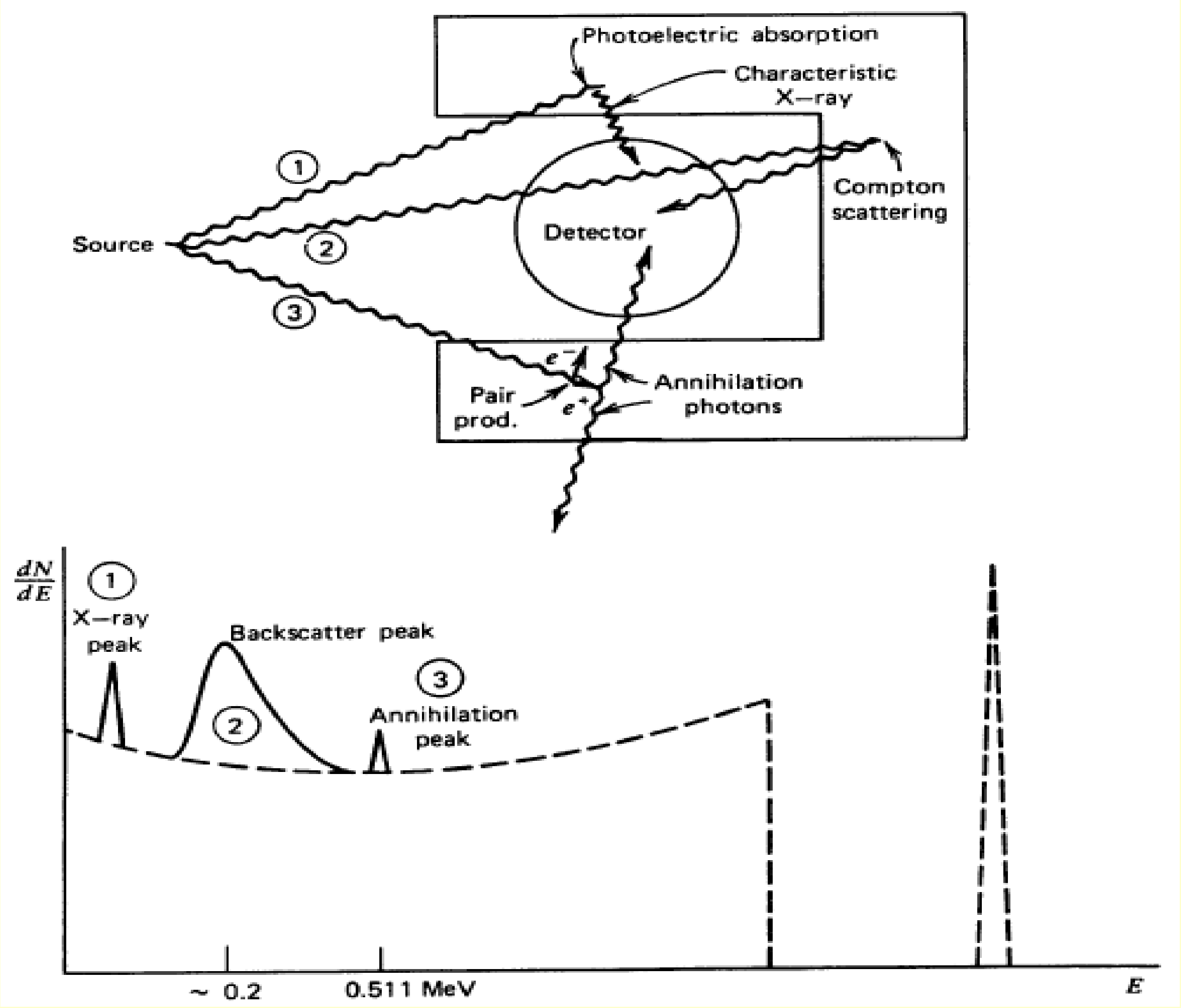




Very large detectors



Effects of surrounding materials



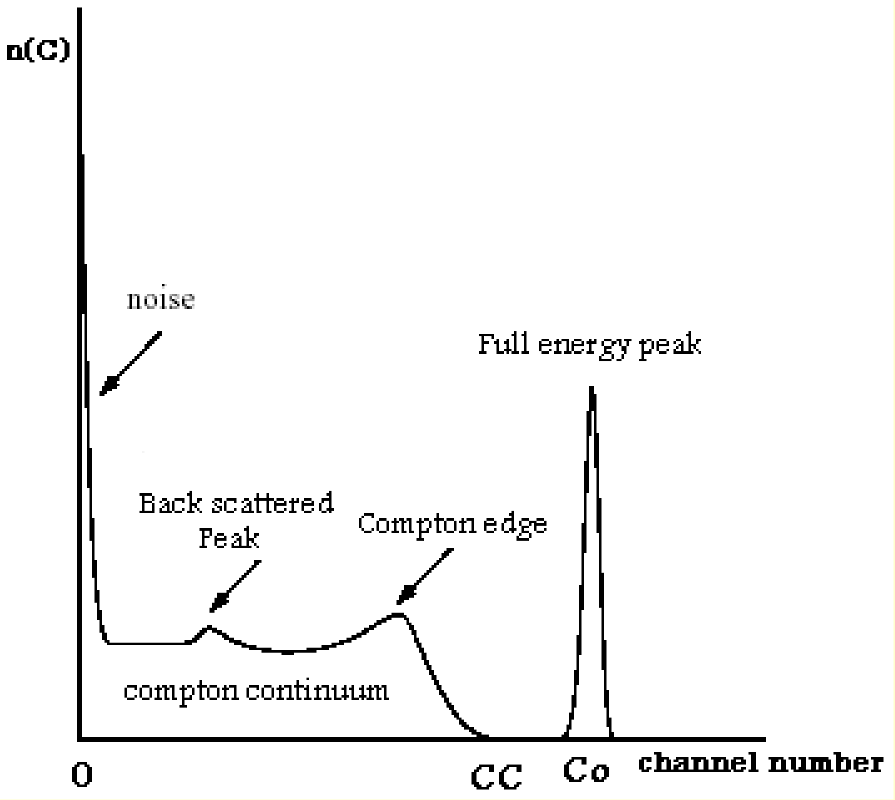
Modes of energy deposition in the detector.

Energy deposition by photons with E_γ<1.022 MeV & E_γ>1.022 MeV

- **The full energy peak.**
- **The Compton edge.**

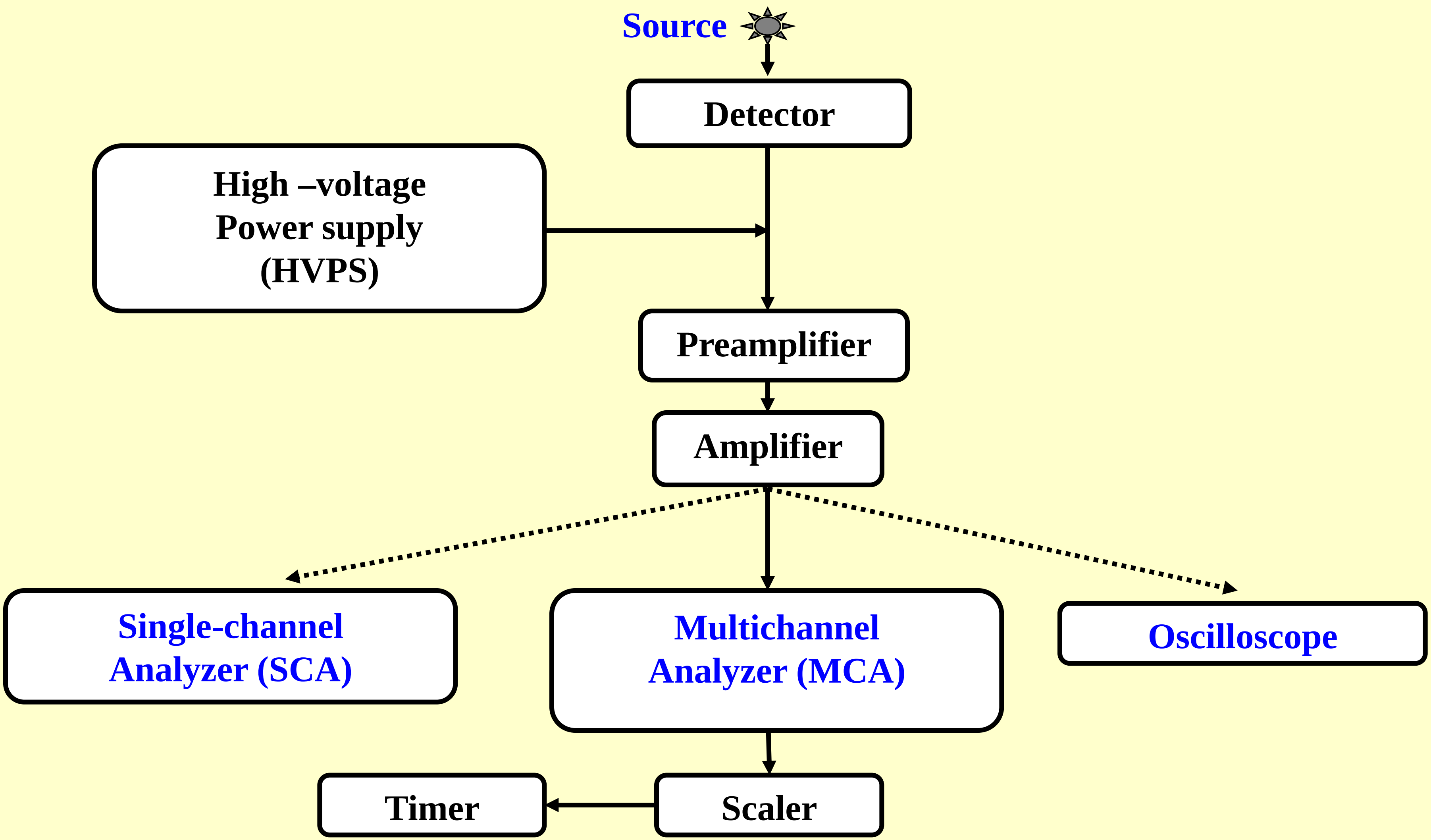
Other peaks may be observed are:

- **Backscatter peak.**
- **The single-escape peak.**
- **The double-escape peak.**



Detection and Recording System

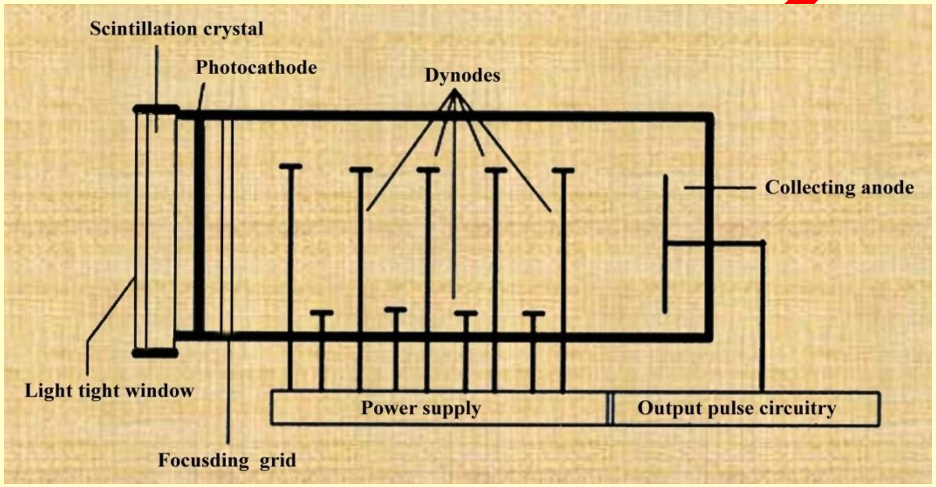
“ Method of Measurements”

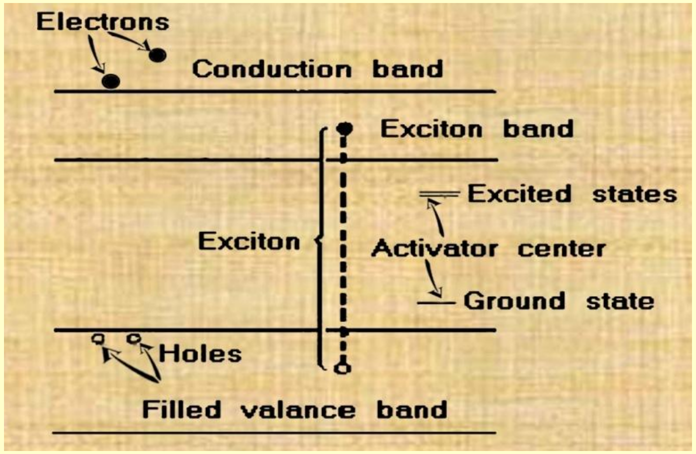


Typical gamma detector.

Types of detectors

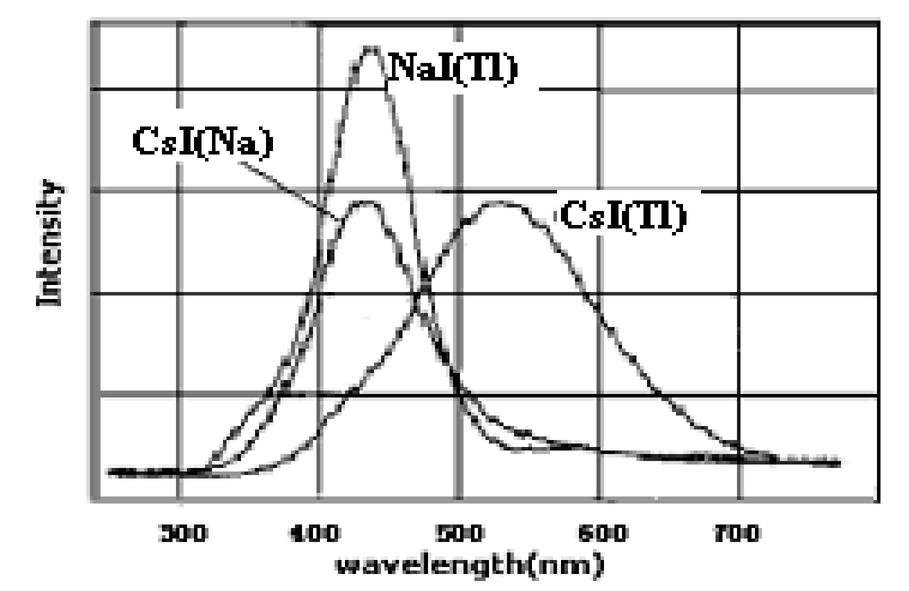
1) Scintillation detectors ➔ The NaI(Tl) scintillation detector.

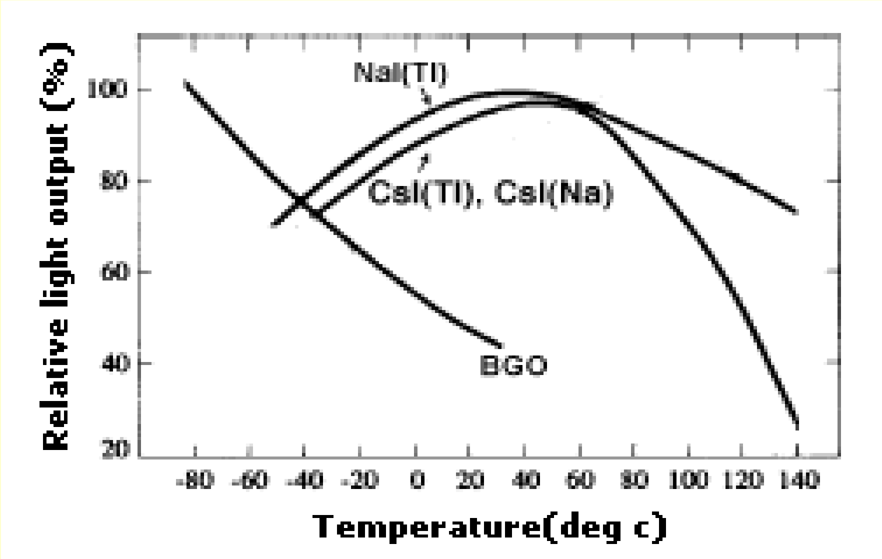


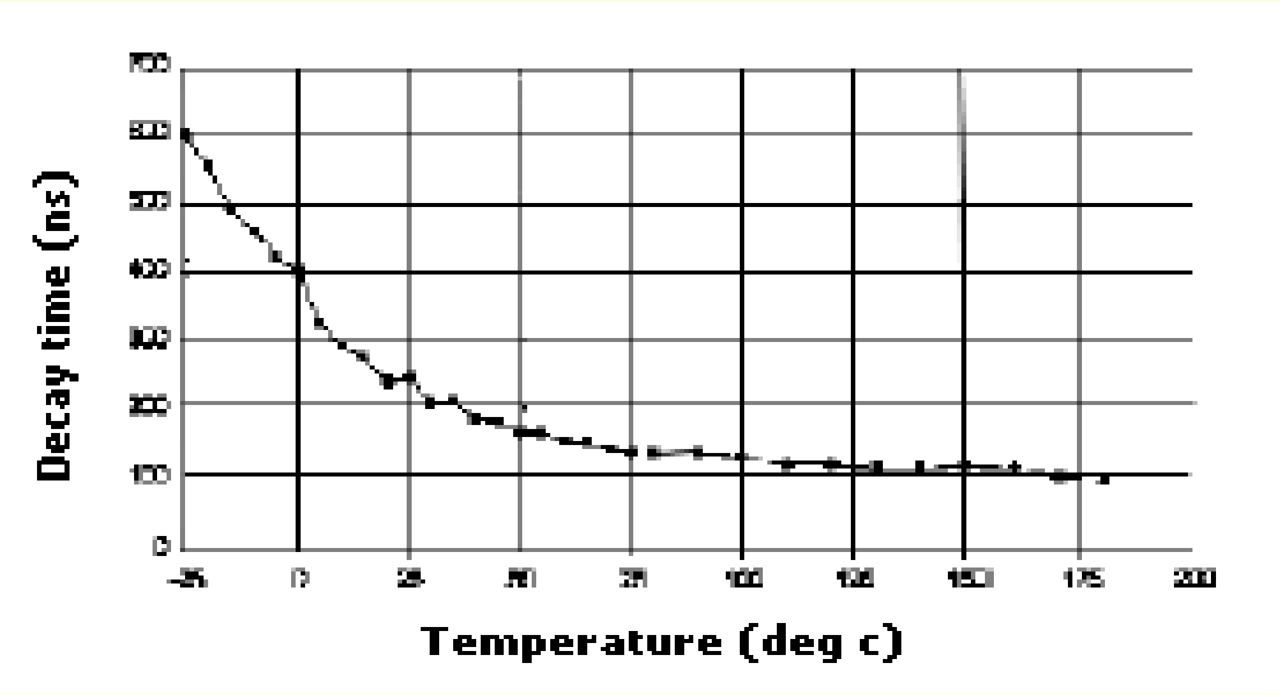


The mechanism of the scintillation process

- **Ionizing radiation passes through the crystal.**
- **Electrons are raised to the conduction band.**
- **Holes are created in the valance band.**
- **Excitions are formed.**
- **Activation centers are raised to the excited states by absorbing electrons, holes and excitons.**
- **De-excitation followed by the emission of photons.**
- **The emission photons interact with the photocathode and electrons are emitted.**
- **The electrons are multiplied by dynodes in photomultiplier tube and finally produced the electric pulse.**

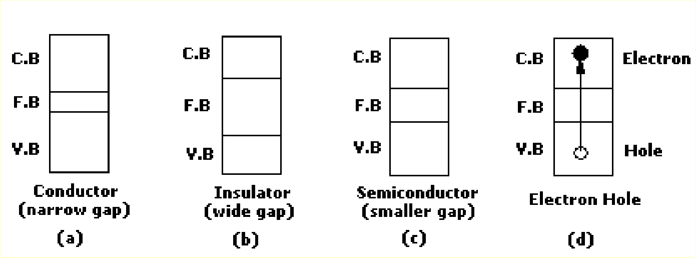

NaI(Tl)
CsI(Na)
CsI(Tl)
Intensity
300
400
500
600
700
wavelength(nm)

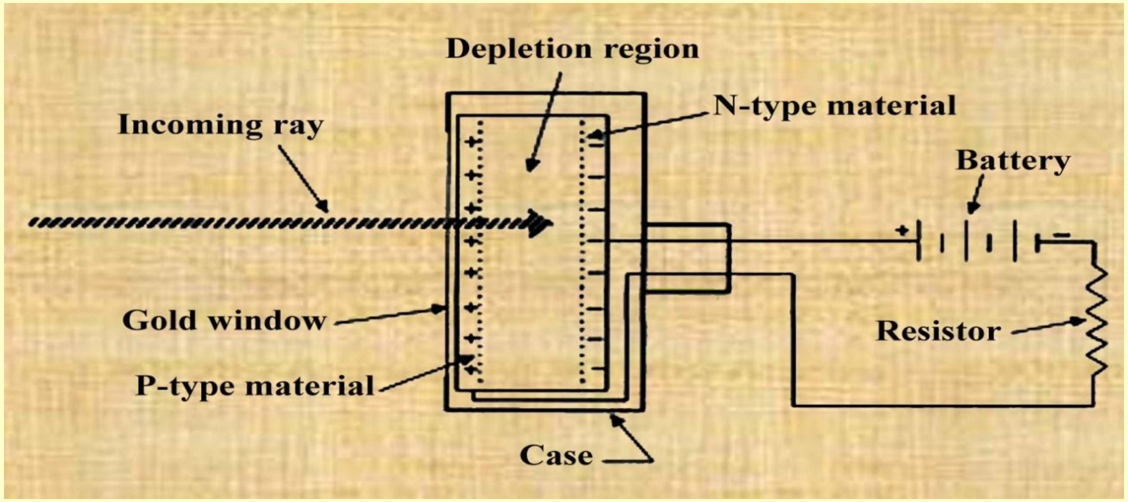

NaI(Tl)
CsI(Tl), CsI(Na)
BGO
Relative light output (%)
100
80
60
40
20
-80
-60
-40
-20
0
20
40
60
80
100
120
140
Temperature(deg c)


Decay time (ns)
Temperature (deg c)

2) Semiconductor detectors

- Germanium lithium detector **(GeLi)**.
- Hyper pure germanium detector **(HPGe)**.



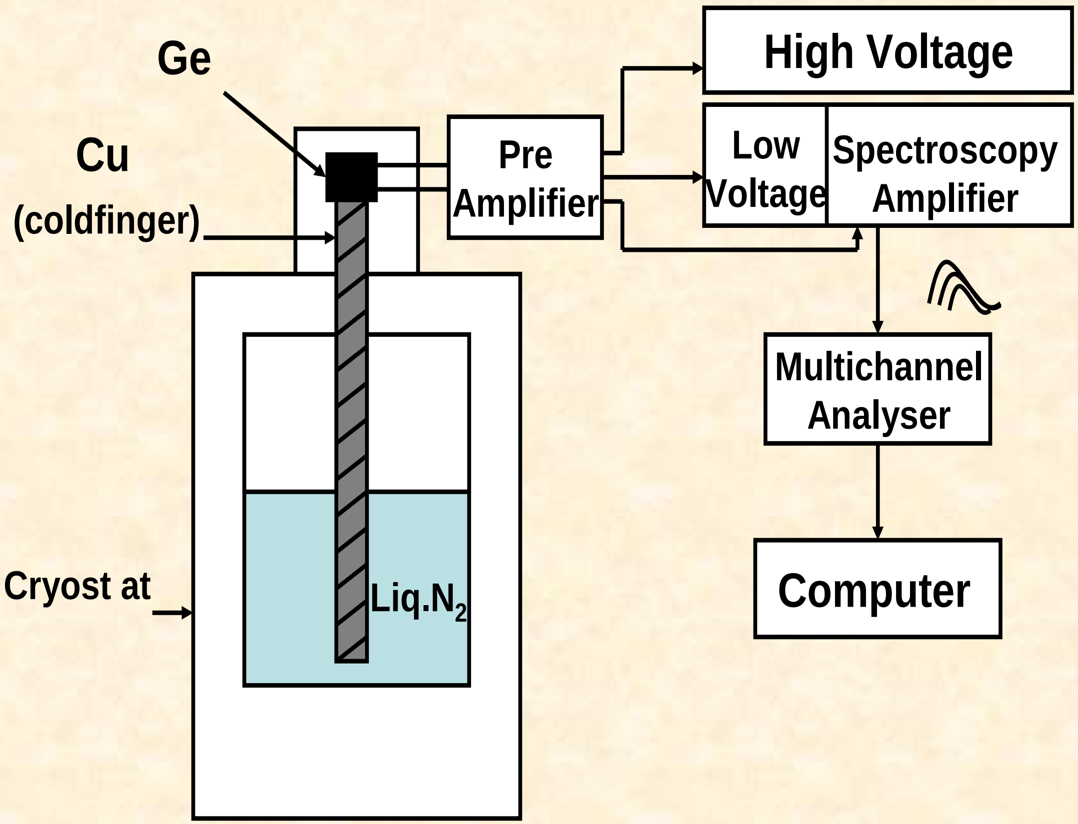


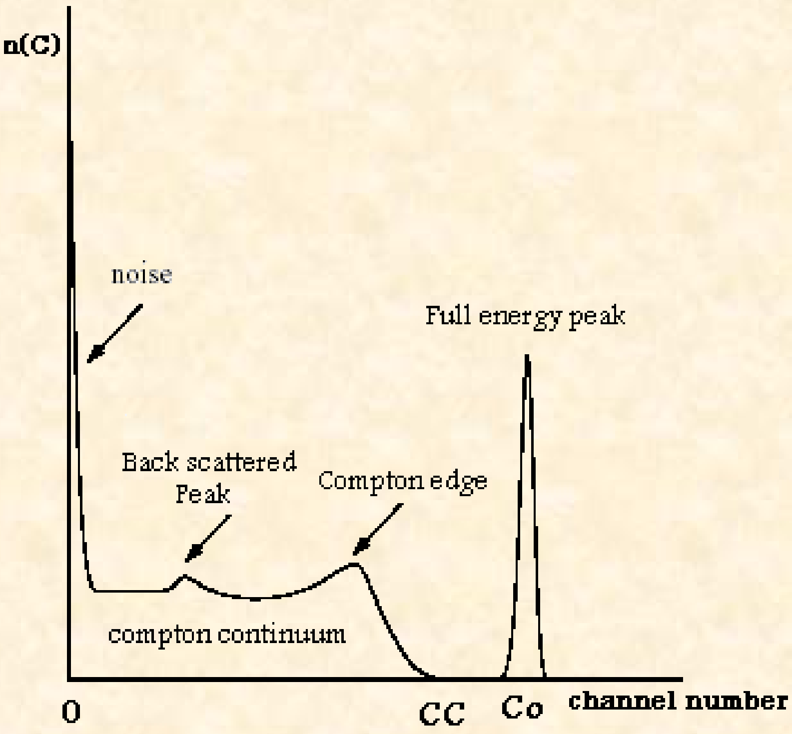
The mechanism of the junction counter

- **Put a suitable external electric field (reverse bias).**
- **Formed the depletion region.**
- **Incoming ray interaction.**
- **Creating electron-hole pairs.**
- **Collection of the electron-hole pairs to produce the electric pulse.**

Detection and recording system
Semiconductor Detectors

Cmoplete HPGe spectrometer

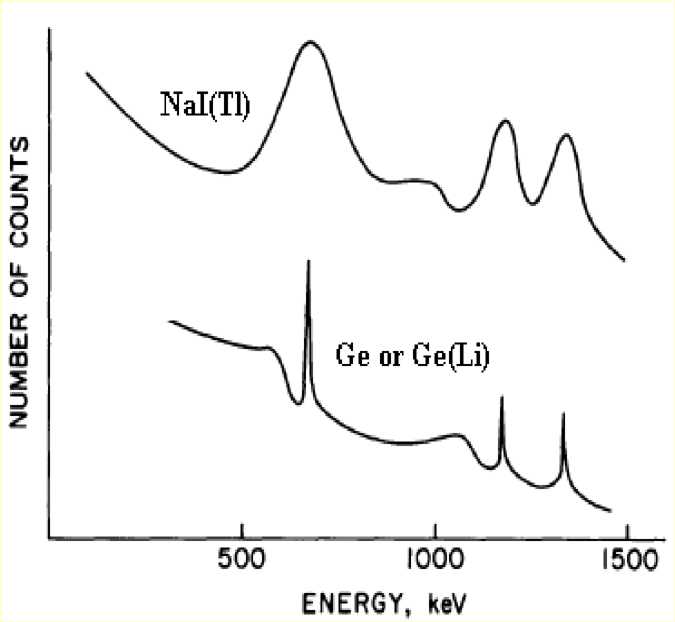




Spectrum Energy Distribution For Photons

Advantages of Ge detectors.

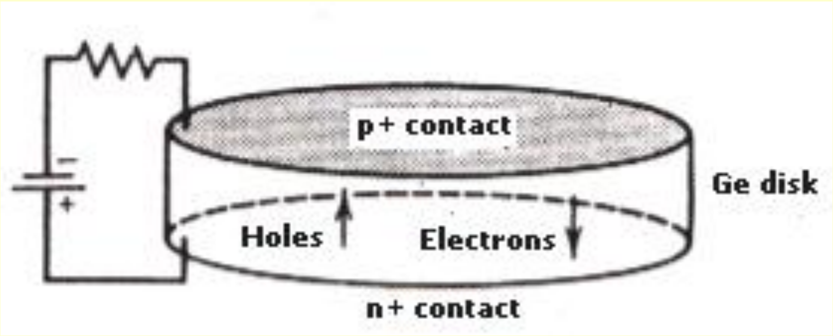
- High resolution & low efficiency.
- Short response time.
- Linear energy response.
- Small crystals size.
- Rise to room temperature.
- don’t need liquid nitrogen.
- Portable detector.
- Very low resistance.



Disadvantages of Ge detectors.

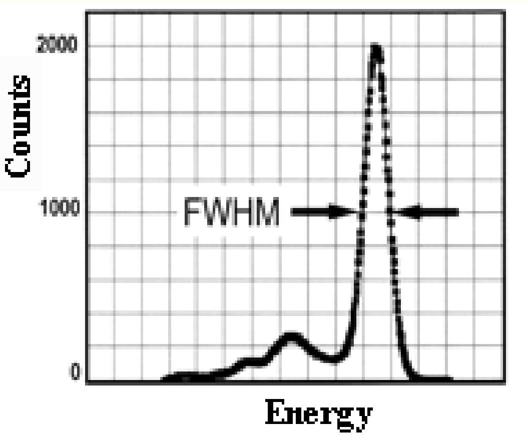
- Used for gamma photon only.
- Need liquid nitrogen.
- Very expensive.
- Small crystals size.
- Good for environmental samples.
- don’t need liquid nitrgen.
- Portable detector.

Planar detector

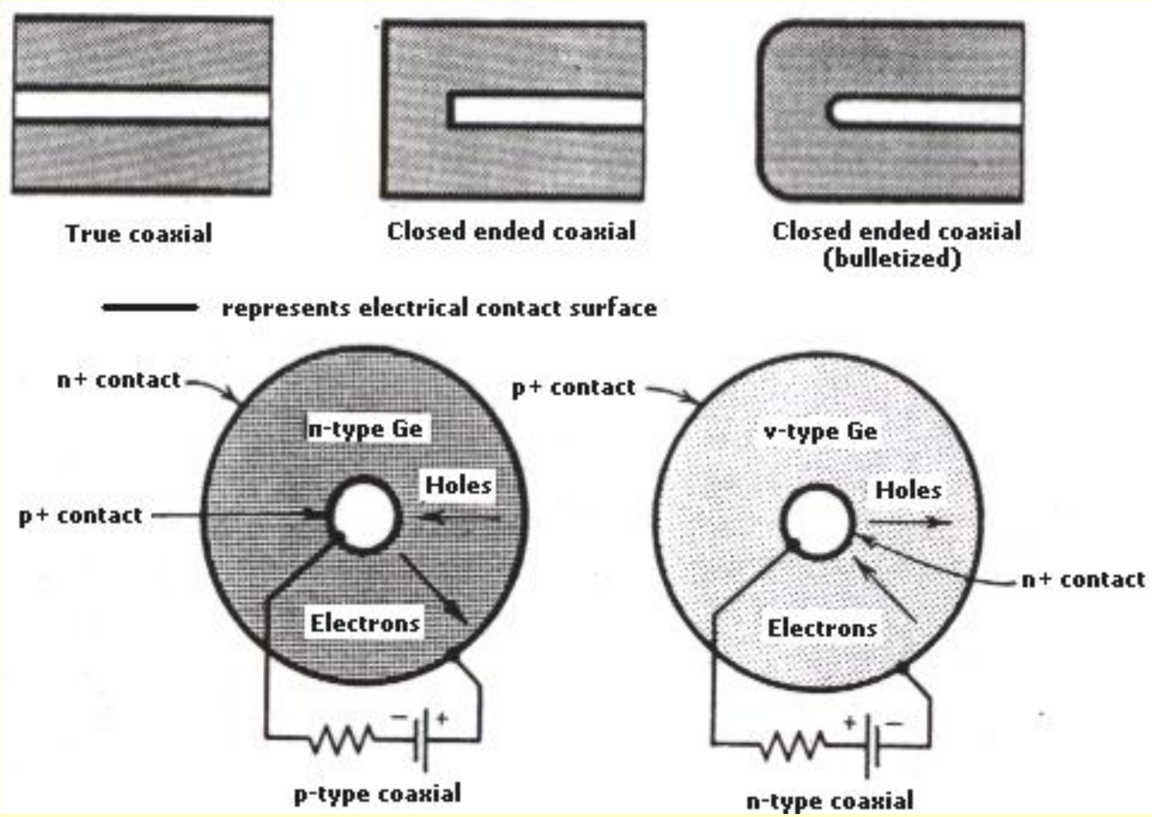


Energy resolution

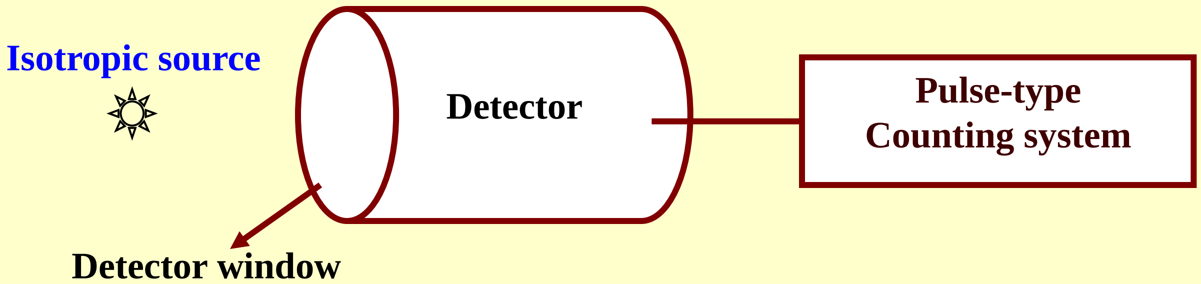
$$\text{Energy resolution} = \frac{\text{FWHM}}{\text{PE}} \times 100\%$$



Coaxial detector



Detectors factors



Let

N = **number of the particles per second emitted by the source.**

r = **number of particles per second recorded by the scaler.**

The counting rate r is related to N by :

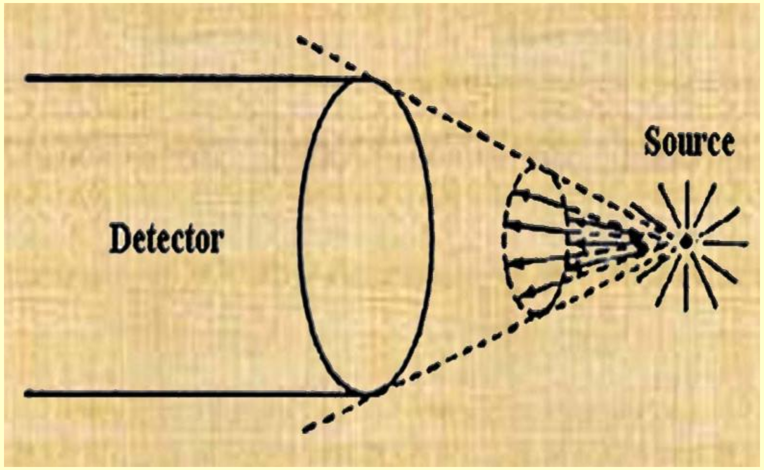
$$r = N.\ f_1 f_2 f_3 \cdots\cdots f_n$$

Where the *f* factors represent the effects of the experimental setup on the measurements. These factors may be grouped into four categories.

❶ Geometry effects.

- **Size and shapes of source (point,disk,rectangular,etc).**
- **Size and shapes of detector (cylindrical,rectangular,etc).**
- **Source-to-detector distance.**

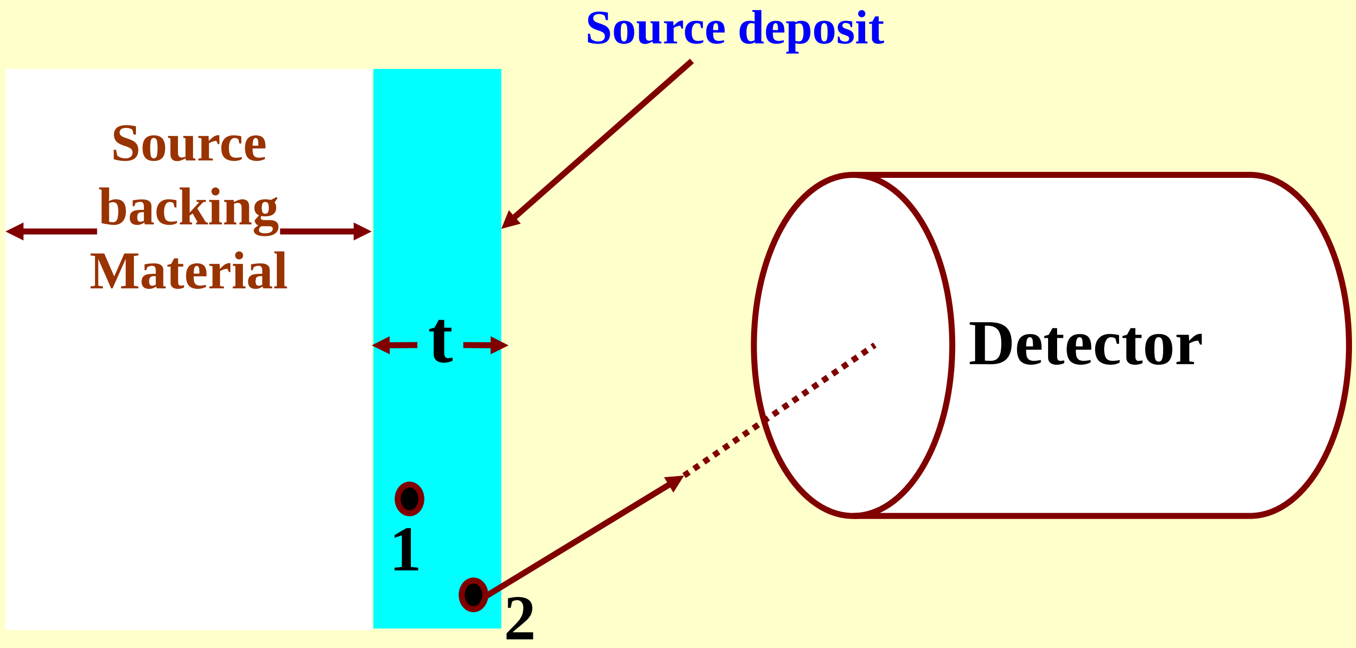
All these factors are included in the solid angle (Ω)



$$\Omega = \frac{\text{number of photons that are enter the detector}}{\text{number of photons that are emitted from the source}}$$

❷ source effects.

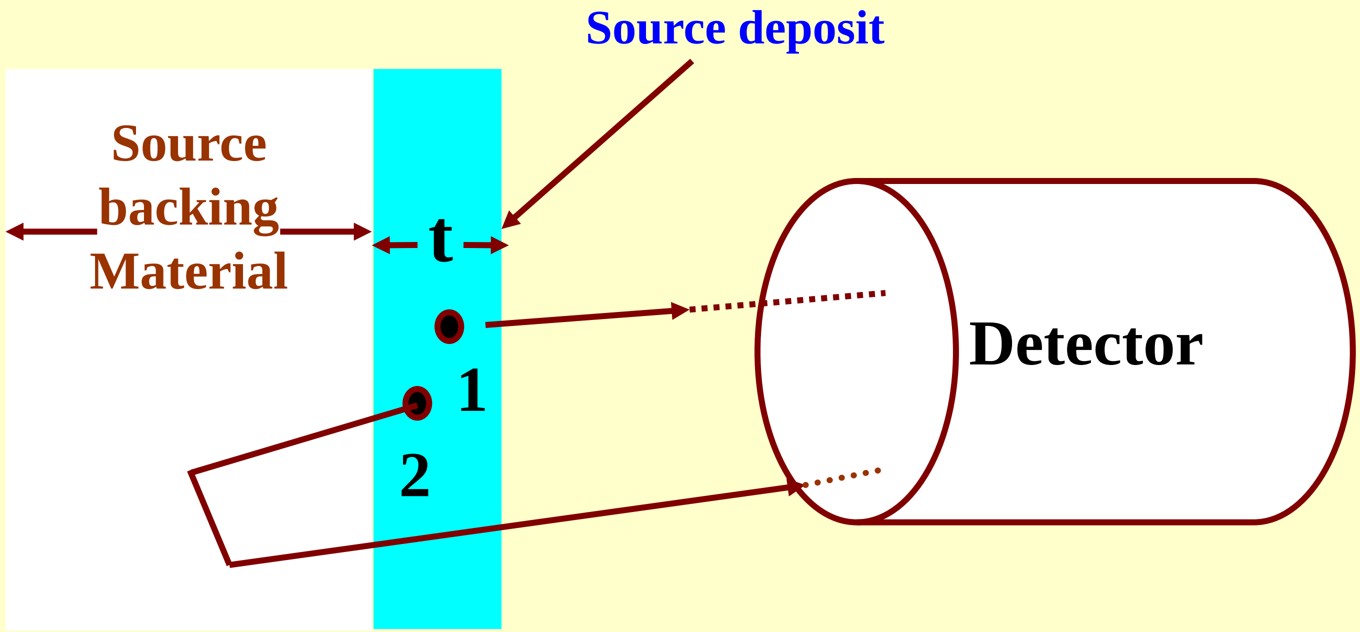
➡ **Source self-absorption factor (f_{self})**



A Source self-absorption factor (f_{self}) is defined by:

$$f_{self} = \frac{\text{number of particles leaving source with self - absorption}}{\text{number of particles leaving source without self - absorption}}$$

Source backscattering factor (f_{back})

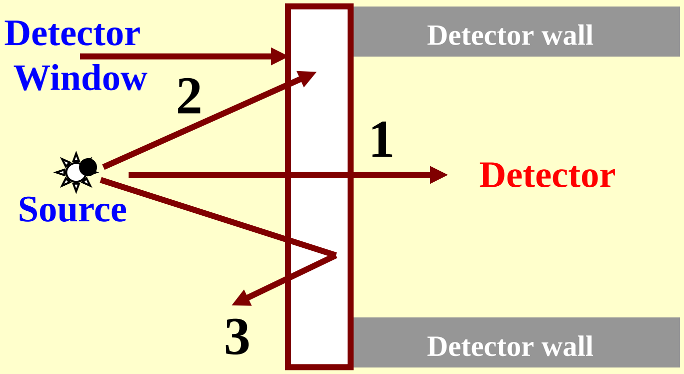


A **Source backscattering factor** (f_{back}) is defined by:

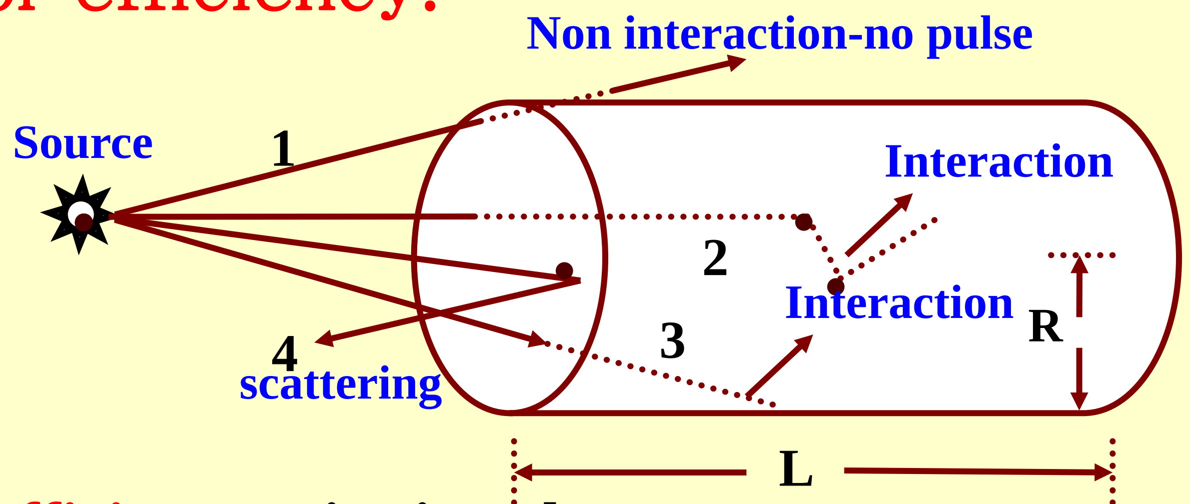
$$f_{back} = \frac{\text{number of particles counted with source backing}}{\text{number of particles counted without source backing}}$$

❸ The medium between source and detector.

- **Thickness of the detector window or any absorber which cause attenuation.**



❹ Detector efficiency.



The detector efficiency ε is given by:

$$\varepsilon = \frac{\text{number of particles recorded per unit time}}{\text{number of particles impining upon the detector per unit time}}$$

Types of the detector efficiency

1) The geometrical efficiency (ε_g).

"The ratio between the number of photons that are enter the detector and the number of photons that are emitted from the source".

$$\varepsilon_g = \frac{\Omega}{4\pi}$$

2) The intrinsic efficiency (ε_{iT}).

"The ratio between the number of photons that are recorded in the detector and the number of photons that are enter the detector".

3) The total efficiency (ε_T).

"The ratio between the number of photons that are recorded in the detector with any possible energy during a certain time interval and the number of photons that are emitted by the source during the same time interval".

$$\varepsilon_T = \varepsilon_g \cdot \varepsilon_{iT}$$

4) The intrinsic phoropeak efficiency (ε_{ip}).

"The ratio between the number of photons that are recorded under a certain energy peak and the number of photons that are enter the detector with the energy relates to this peak".

5) The full energy peak efficiency (FEPE)(ε_p).

"The ratio between the number of photons that are recorded under a certain energy peak and the number of photons that are emitted from the source with the energy relates to this peak".

$$\varepsilon_p = \varepsilon_g . \varepsilon_{ip}$$

6) The single escape peak efficiency (ε_{se}).

"The ratio between the number of single escape photons and the number of photons that are emitted from the source".

7) The double escape peak efficiency (ε_{de}).

"The ratio between the number of couple photons escape and the number of photons that are emitted from the source".

8) The photo-fraction (peak-to-total ratio)(**p**).

"The ratio between the number of photons that are recorded under a certain energy peak and the number of photons that are recorded in all the spectrum at the same energy".

$$P = \frac{\varepsilon_{ip}}{\varepsilon_{iT}} = \frac{\varepsilon_{p}}{\varepsilon_{T}}$$

9) The relative efficiency.

$$(\text{Relative efficiency})_i = \frac{(\text{The efficiency of the detector})_i}{\text{Efficiency of the standard detector}}$$

Where the subscript i refers to any one of the efficiencies defined before. (The standard detector is a 3"x 3 " NaI(Tl) detector. The efficiency is measured for photon with energy 1.33 MeV and source-to-detector distance 25 cm)

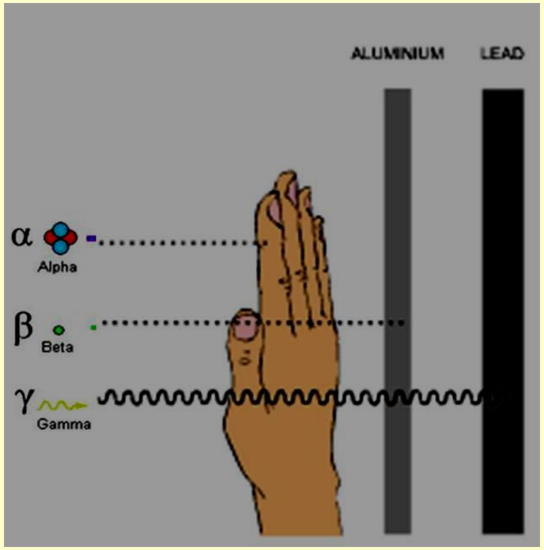
Alpha Particles

- The alpha particle is a helium nucleus (2 protons, 2 neutrons) produced from the radioactive decay of heavy metals and some nuclear reactions.

- The high positive charge (2+) of an alpha particle causes electrical excitation and ionization of surrounding atoms.

- Alpha particles are the least penetrating radiation featuring a relatively straight path over a short distance (several cm in air).

- The specific ionization of alpha particles is very high.



Beta Particles

- There are two types of beta particles: electron (β^-) and positron (β^+). These are ejected from the nucleus of a beta-unstable radioactive atom .

- The beta has a single negative or positive electrical charge and very small mass.

- The interaction of a beta particle and an orbital electron leads to electrical excitation and ionization of the orbital electron.

- Beta particles follow a tortuous path (zig-zag).

- The specific ionization of a beta particle is low due to its small mass, small charge, and relatively high speed of travel.

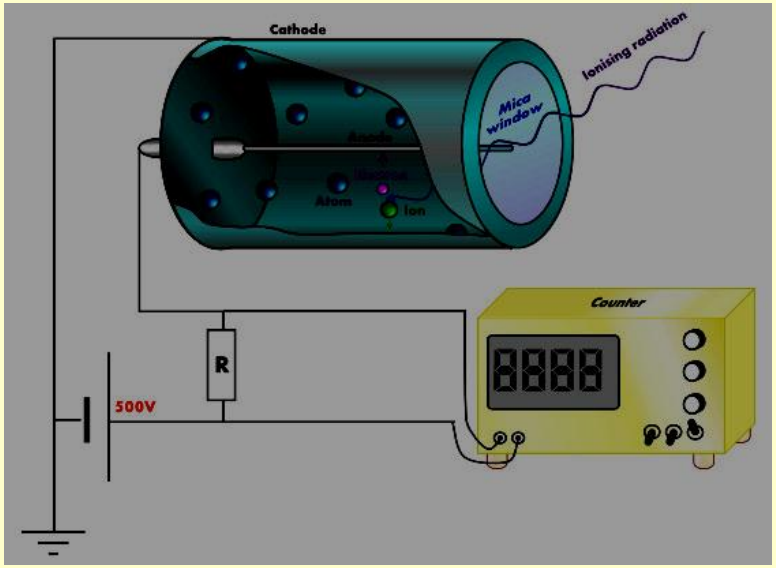
- The interaction of β^+ (positron) with an electron leads to their annihilation and occurrence of two annihilation photons with the energy of 0.511 MeV.

Neutrons

- **Neutrons have no electrical charge and have nearly the same mass as a proton.**

- **Neutrons are fairly difficult to stop, and have a relatively high penetrating power.**

Gas-Filled Detector



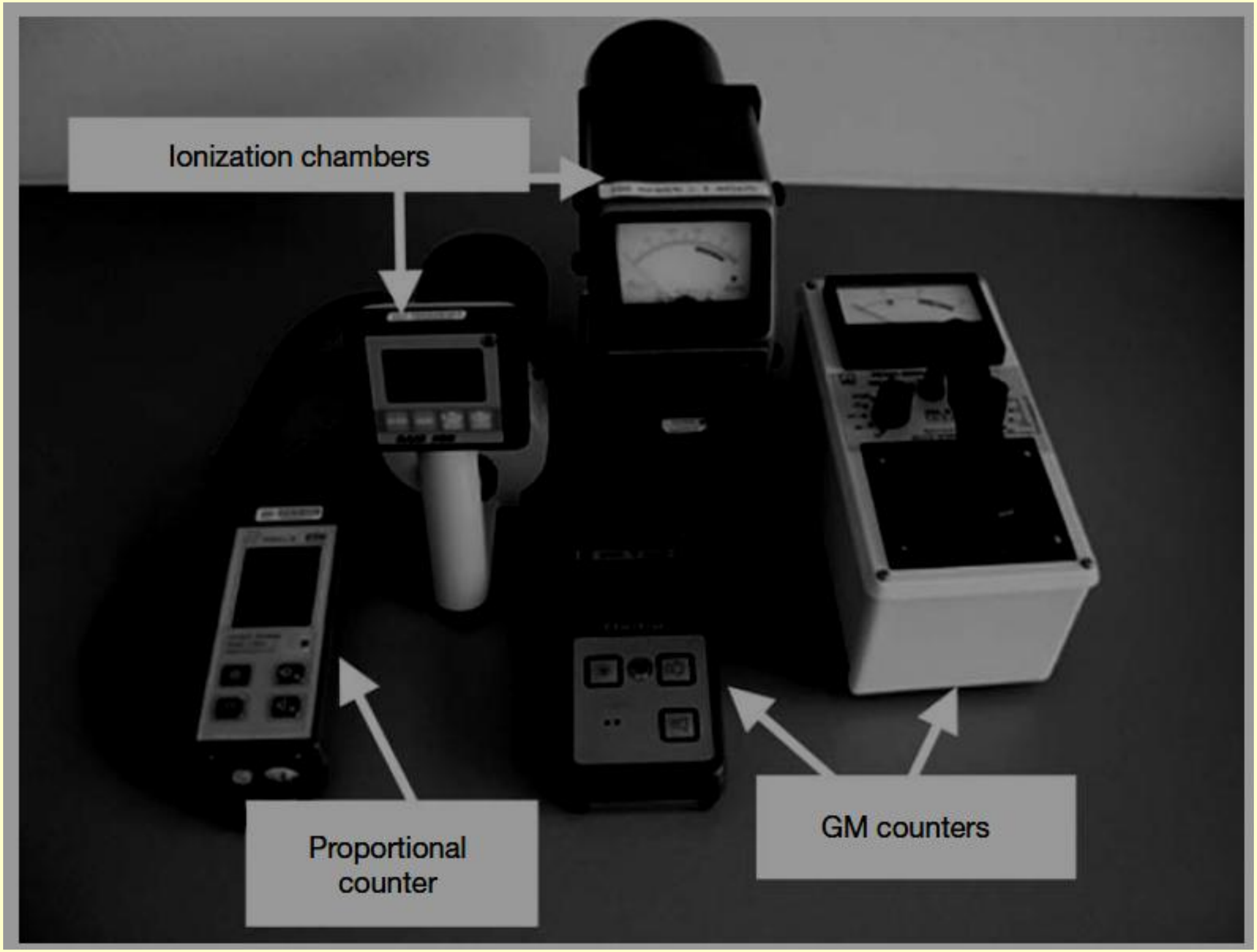
$$\Delta V = \Delta Q / C$$

The central electrode, or **anode**, attracts and collects the electron of the ion-pair.

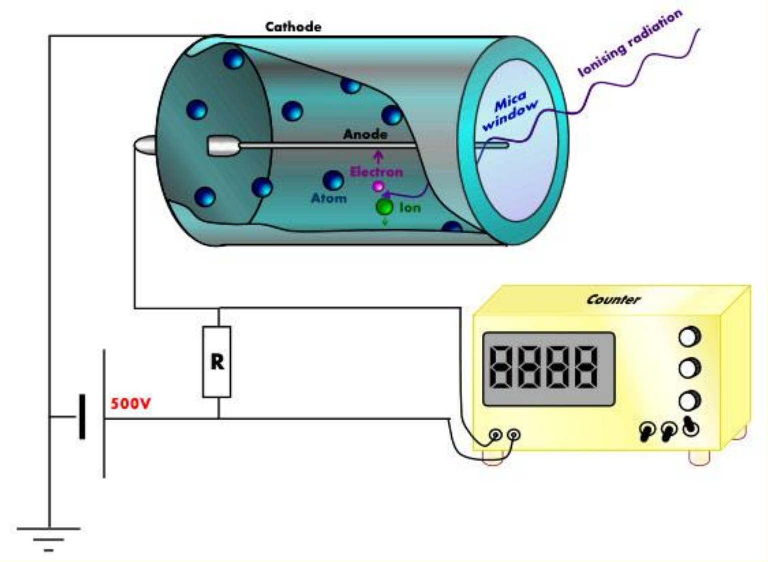
The chamber **walls** attract and collect the positive ion.

When the applied voltage is high enough, the ion pairs initially formed accelerate to a high enough velocity to cause secondary ionizations. The resultant ions cause further ionizations. This multiplication of electrons is called **gas amplification**.

Gas Counters



Properties of Gas-Filled Detector



$\Delta V = \Delta Q/C$

- The pulse height can be computed if the capacitance, detector characteristics, and radiation are known.
- The capacitance is normally about 10^{-4} farads.
- The number of ionizing events may be calculated if the detector size and specific ionization, or range of the charged particle, are known.
- The only variable is the gas amplification factor that is dependent on applied voltage.

Detector Voltage

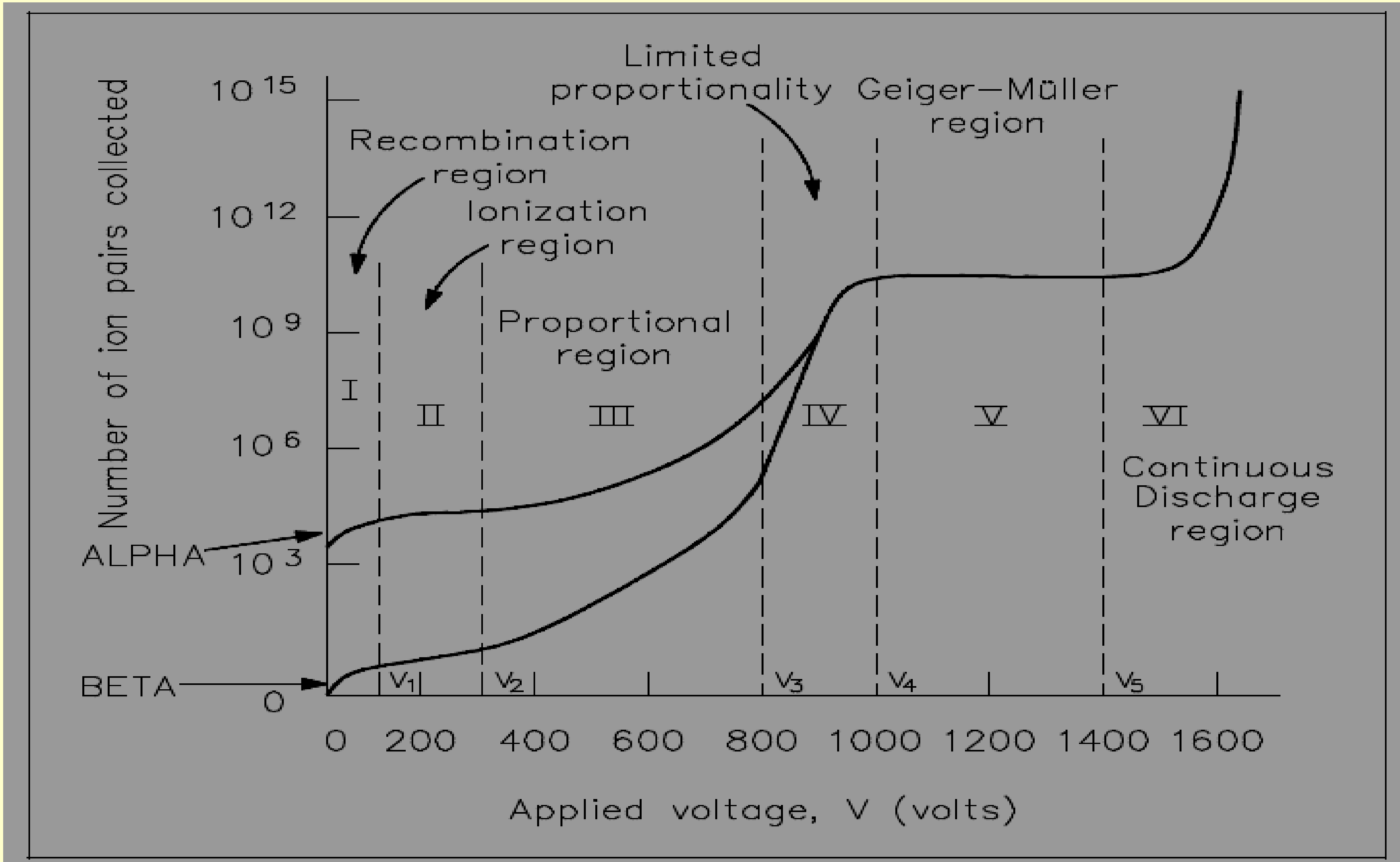
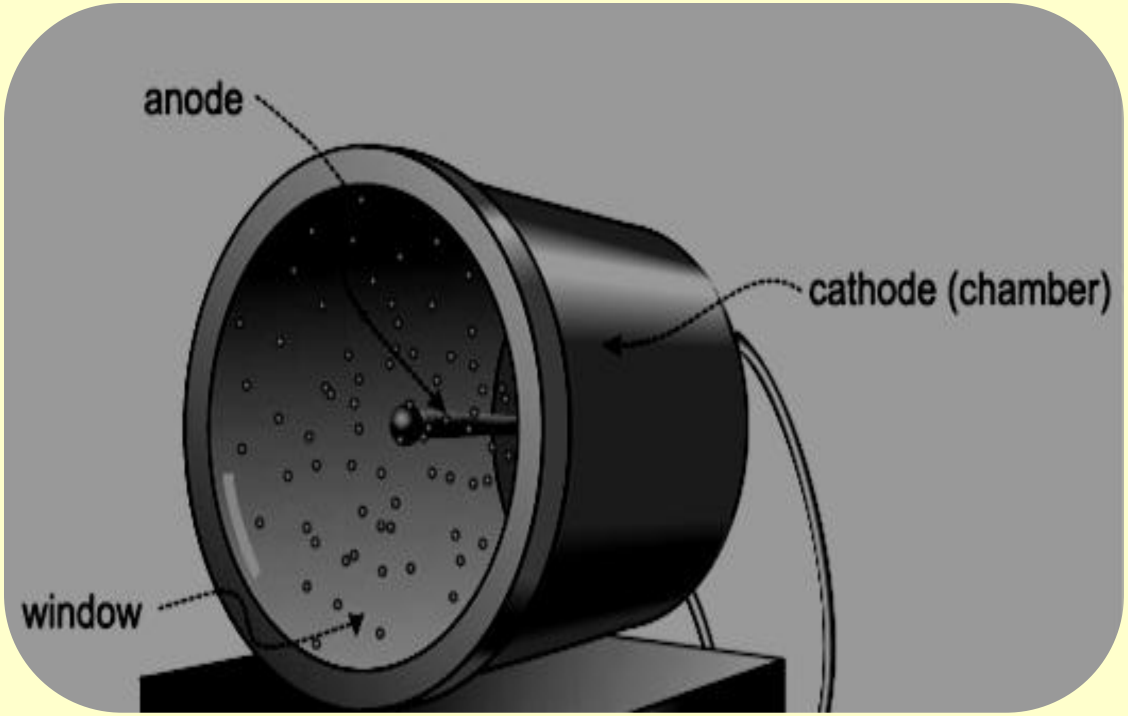


Figure 6 Ion Pairs Collected -vs- Applied Voltage

Detector Time



Resolving time is the time required by the detector to regain its normal state after registering a pulse

Dead time is the time during which the second pulse could not be detected, It is caused by the slow movement of the positive ions away from the anode

Recombination Region

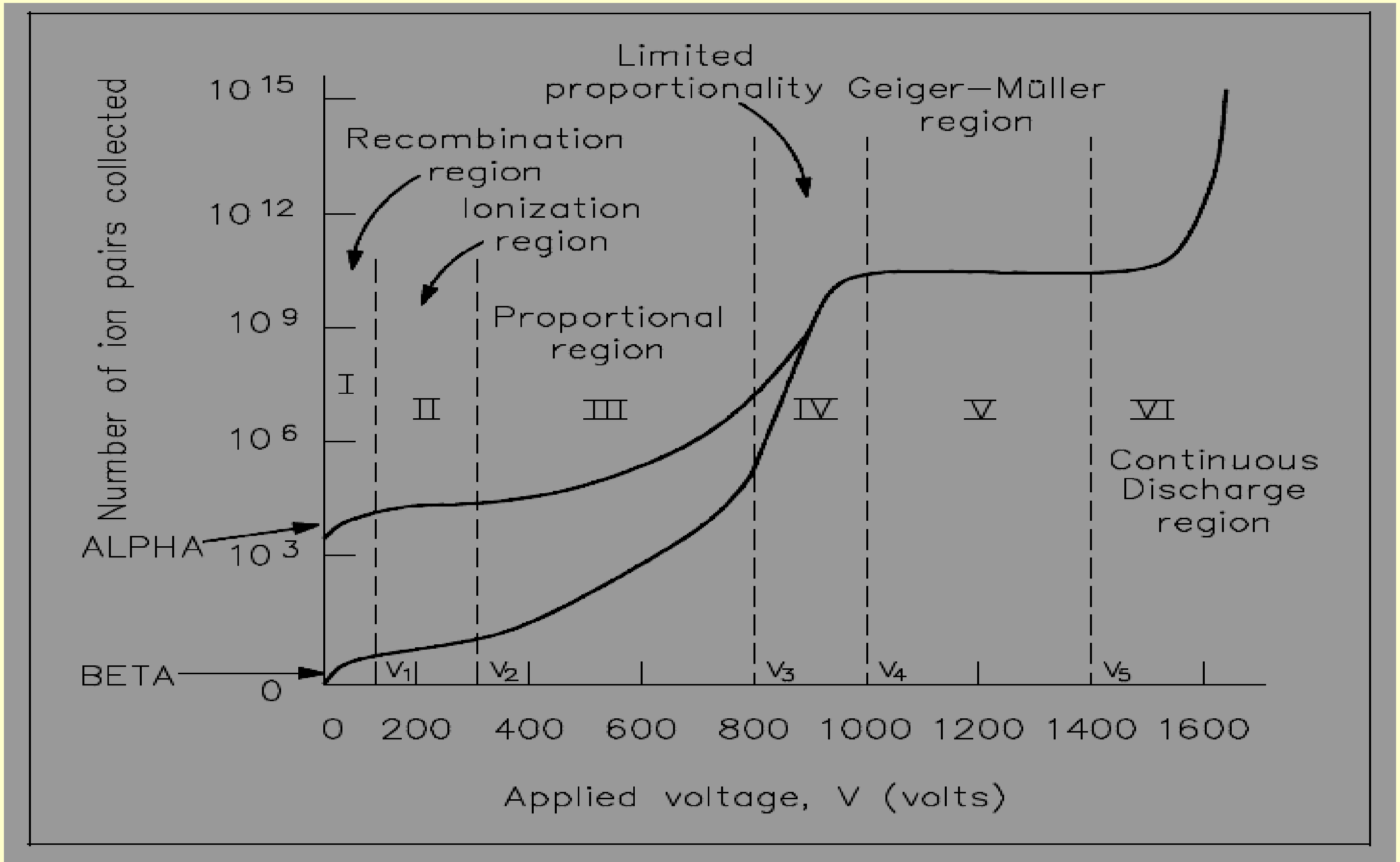


Figure 6 Ion Pairs Collected -vs- Applied Voltage

- voltage so low that recombination takes place before any charge is collected at the electrodes

- no counters operate in this region

Ionization Region

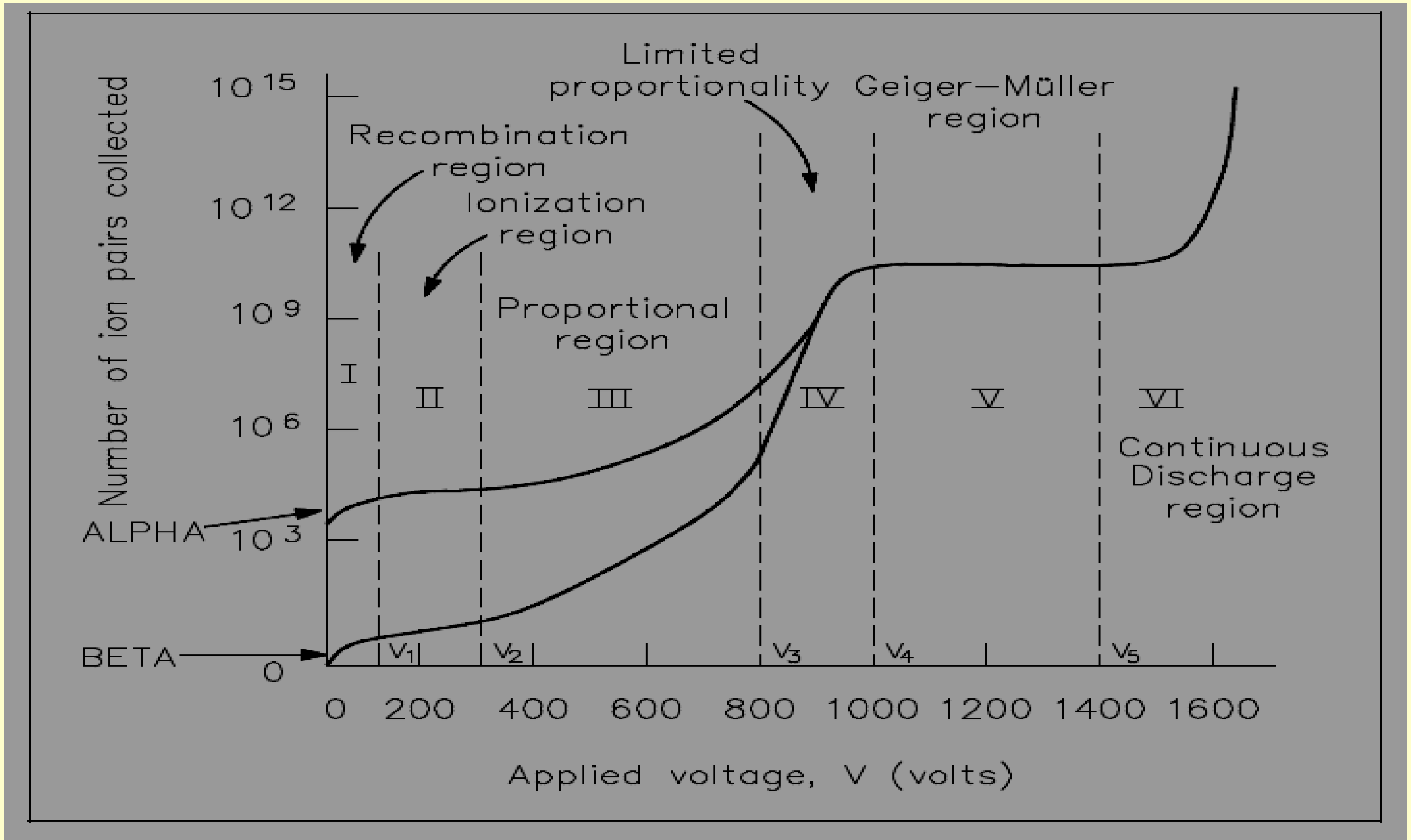
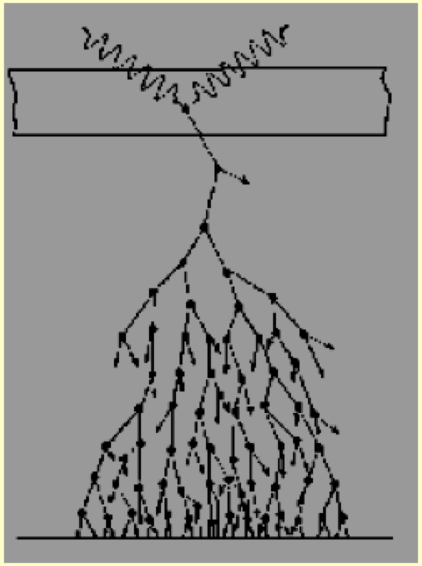


Figure 6 Ion Pairs Collected -vs- Applied Voltage

- voltage sufficient to ensure that **all electron-ion pairs** produced by the incident radiation are **collected**
- **no gas amplification** takes place

The Height of the Pulse



$$\Delta V = Ane/C$$

ΔV = pulse height (volts)
A = gas amplification factor
n = initial ionizing events
e = charge of the electron (1.602×10^{-19} coulombs)
C = detector capacitance (farads)

A = number of ions **collected** / number of **initial** ions

Fill Gas - **A noble gas** which occupies 90 to 95% of the active volume of the detector. The noble gas is typically **helium, neon, or argon**.

Quench Gas - A gas occupying 5 to 10% of the detector volume. The quench gas functions to **prevent the formation of spurious pulses**.

Ionization Detector

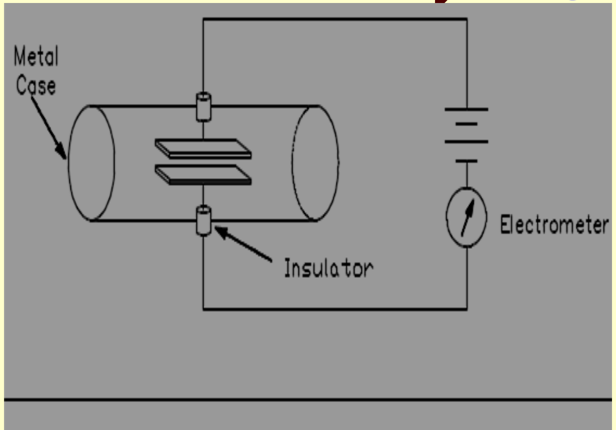


Figure 16 Ionization Chamber

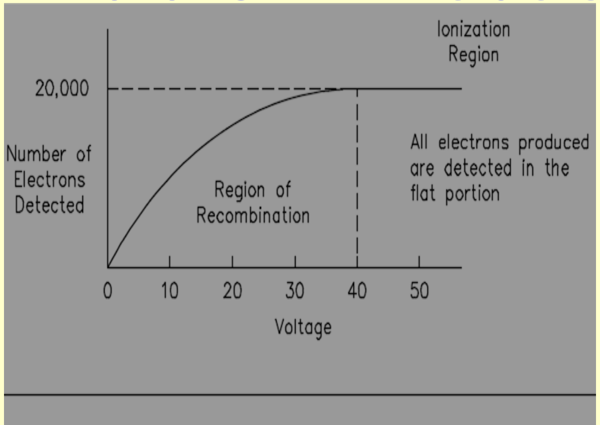
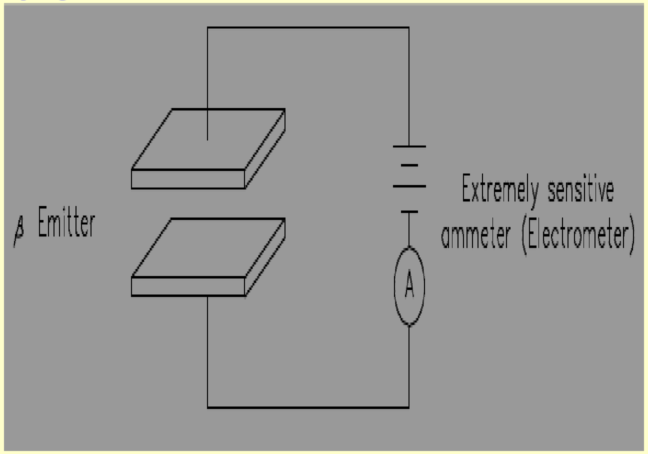


Figure 15 Recombination and Ionization Regions



- **When radiation enters an ionization chamber, the detector gas at the point of incident radiation becomes ionized.**

- **Some of the electrons have sufficient energy to cause additional ionizations.**

- **The electrons are attracted to the electrode by the voltage potential set up on the detector.**

- **If the voltage is set high enough, all of the electrons will reach the electrode before recombination takes place.**

Ionization Chamber Detector for Neutrons

$$^{10}_{5}B + ^{1}_{0}n \rightarrow ^{7}_{3}Li^{+++} + ^{4}_{2}He^{++} + 5e^{-}$$

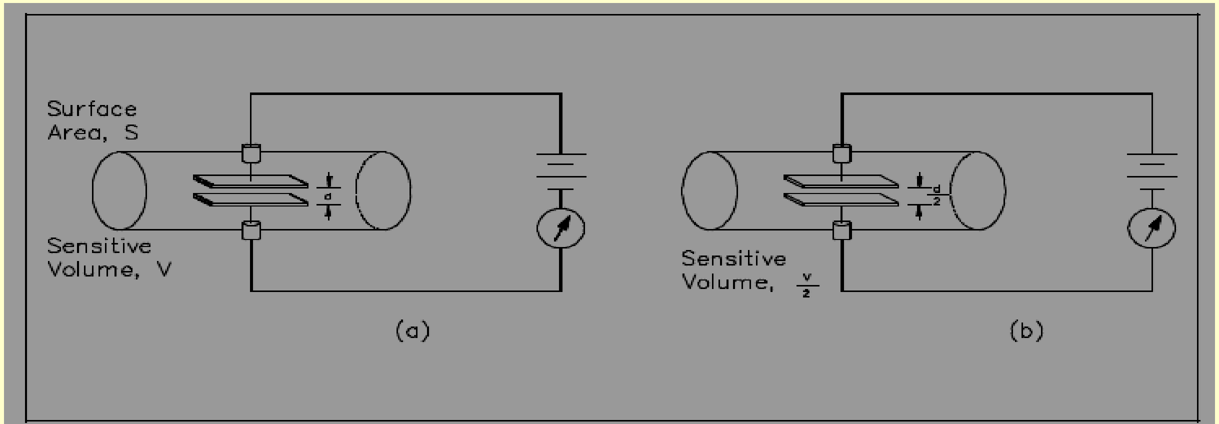


Figure 17 Minimizing Gamma Influence by Size and Volume

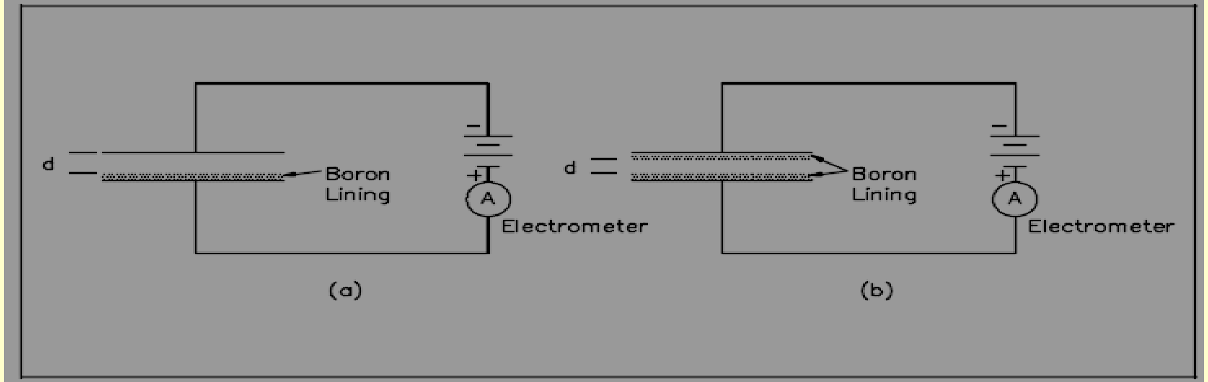
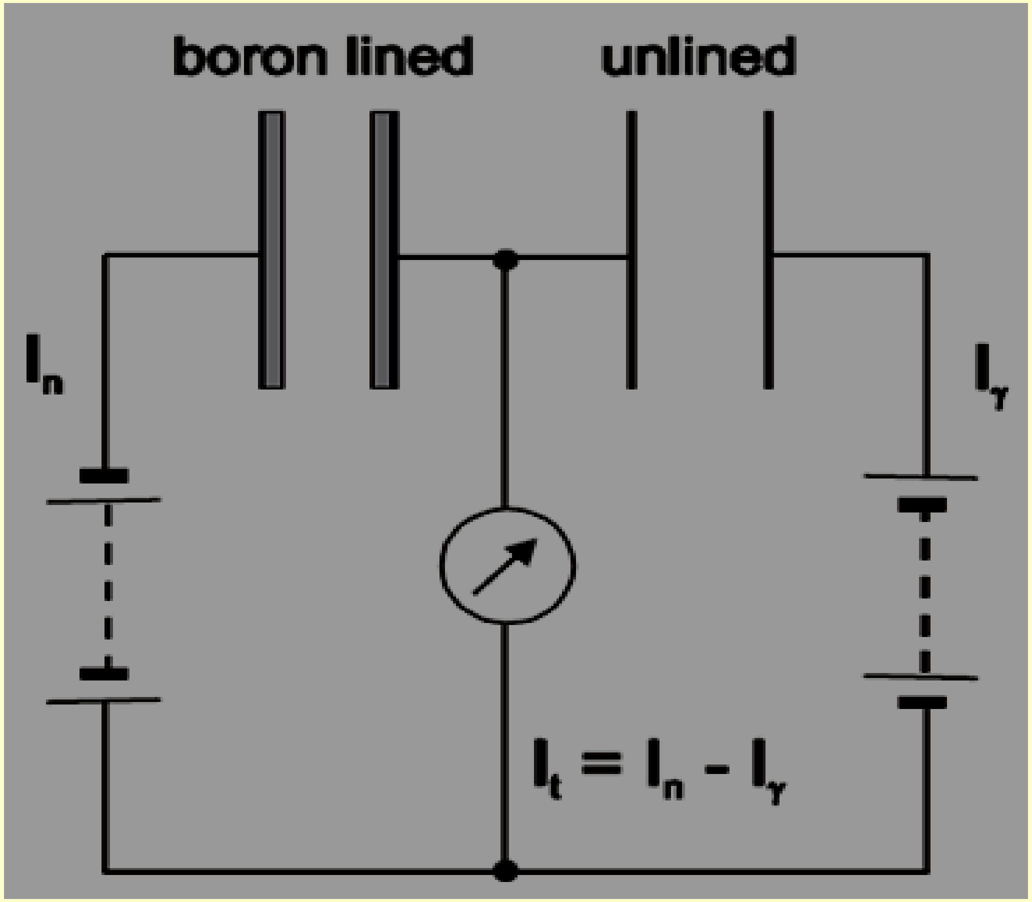


Figure 18 Minimizing Gamma Influence with Boron Coating Area

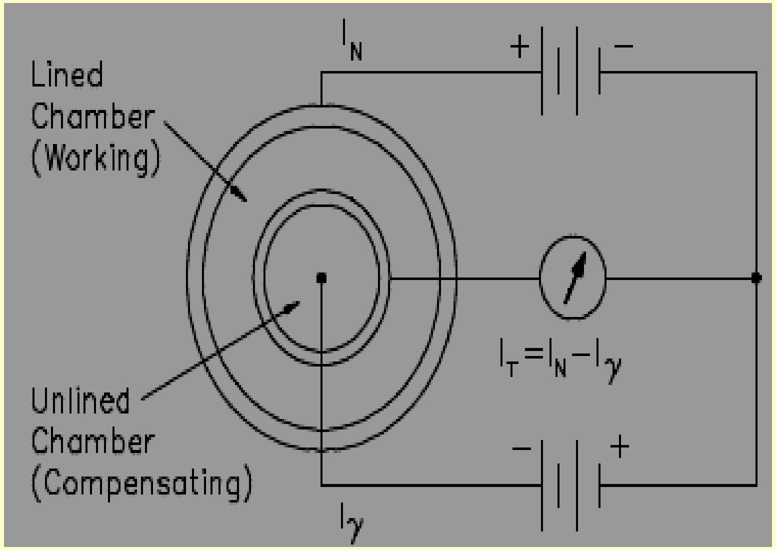
- **Gamma sensitivity reduction is accomplished by either reducing the amount of chamber gas or increasing the boron coated surface area.**

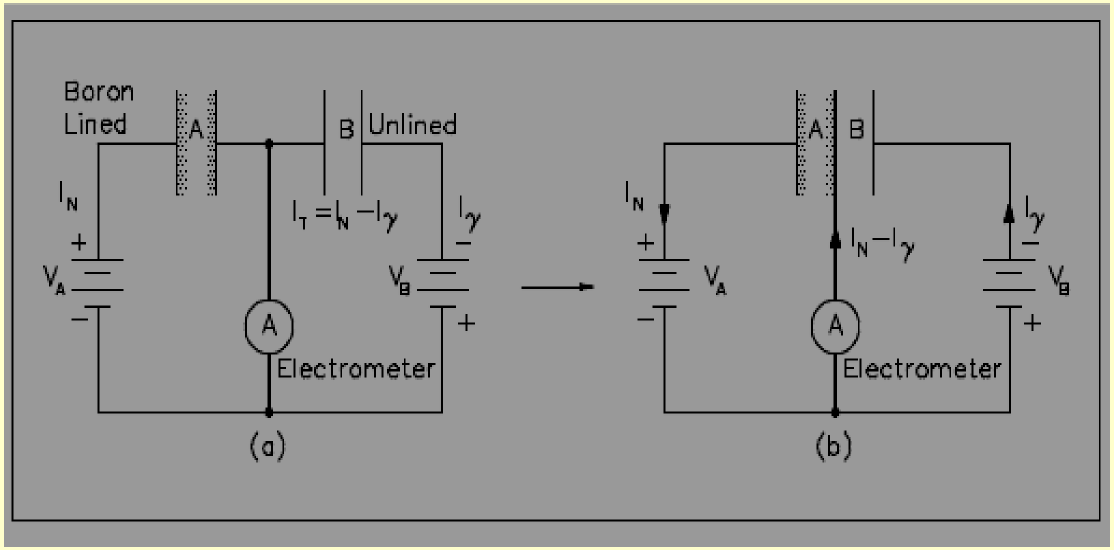
Compensated Ionization Chamber



The boron coated chamber is referred to as the working chamber; the uncoated chamber is called the compensating chamber.

Compensated Ionization Chamber





◙ **A compensated ion chamber has two concentric cylinders: a boron-coated chamber and an uncoated chamber.**

◙ **Both gammas and neutrons interact in the boron-coated chamber.**

◙ **Only gammas interact in the uncoated chamber.**

◙ **The voltages to each chamber are set so that the current from the gammas in the boron-coated chamber cancels the current from the gammas in the uncoated chamber.**

Compensated Ionization Chamber

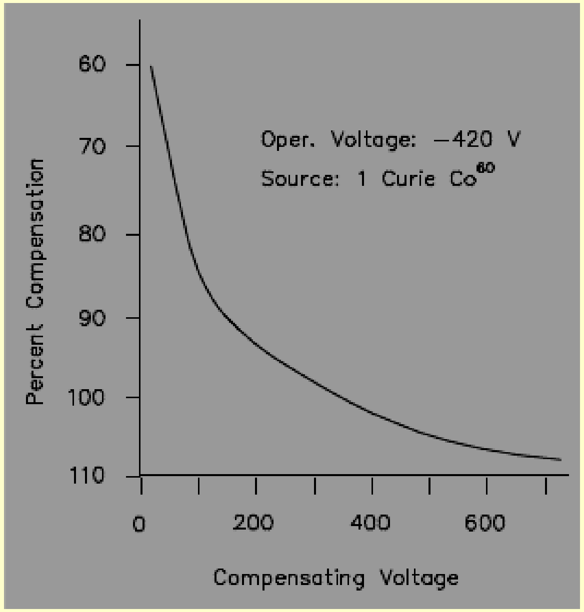
Percent compensation of a compensated ion chamber gives the percentage of the gamma rays which are canceled out. Percent compensation may be calculated based on measured current, when the detector is exposed to gamma rays only

$$\text{Percent Compensation} = 1 - \frac{I_{measured}}{I_{operating}} \times 100\%$$

where

$I_{measured}$ = measured current (milliamps)

$I_{operating}$ = measured current with compensating voltage OFF (milliamps)



If measured current is zero, then percent compensation is 100%.

If measured current is positive, the percent compensation is less than 100%, and the chamber is undercompensated.

If the measured current is negative, the percent compensation is greater than 100%, and the chamber is overcompensated.

Ionization Detector Properties

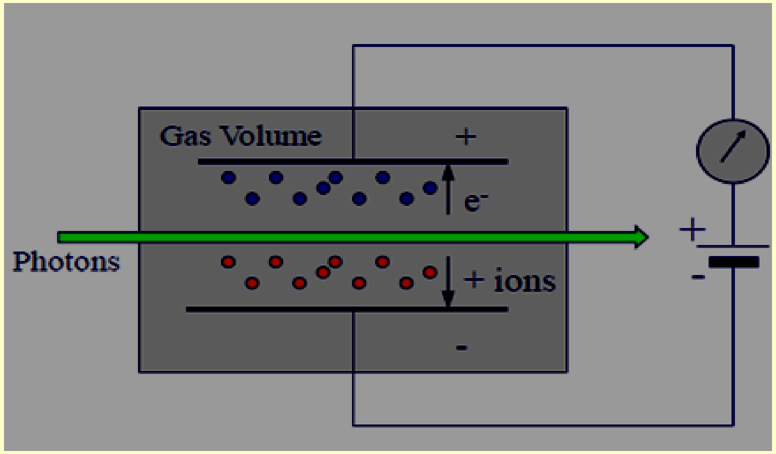
- **output signal proportional to the particle energy => identification of the type of particle and its energy**

- **signal is not large => only strongly ionizing particles (α, p, fission fragments, heavy ions) are detected**

- **energy range > 10 keV**

- **pulse counting ionization chamber and integrating ionization chamber**

- **parallel plate or concentric cylinder design, gas: air**

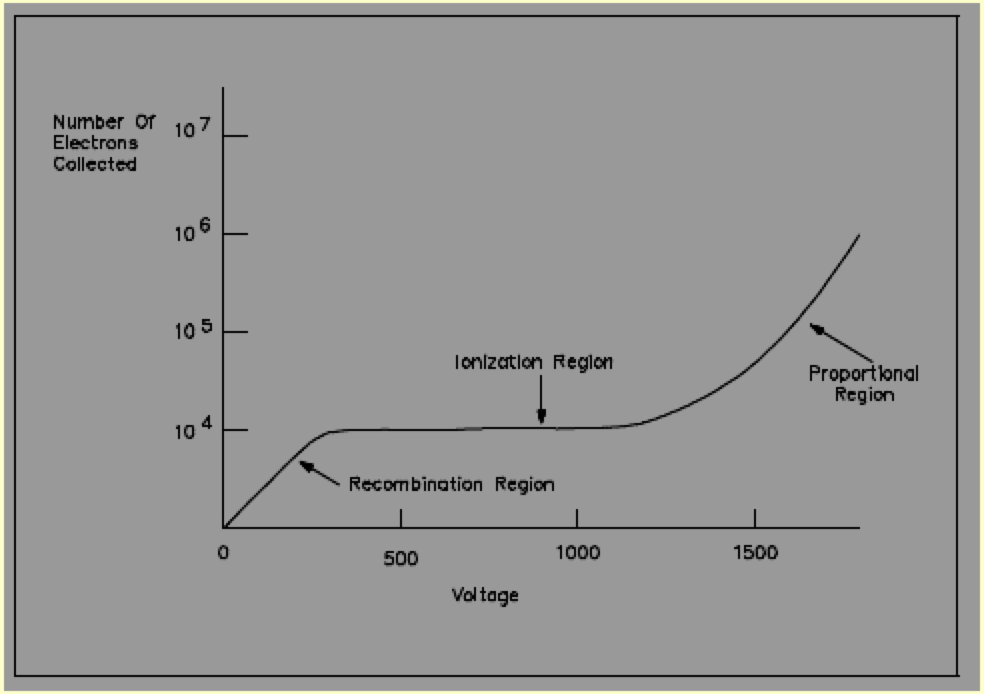


- **"window" for α and/or β**

- **detection of neutrons**

- **gamma sensitivity is reduced by decreasing the amount of chamber gas or increasing the boron coated surface area**

Proportional Region



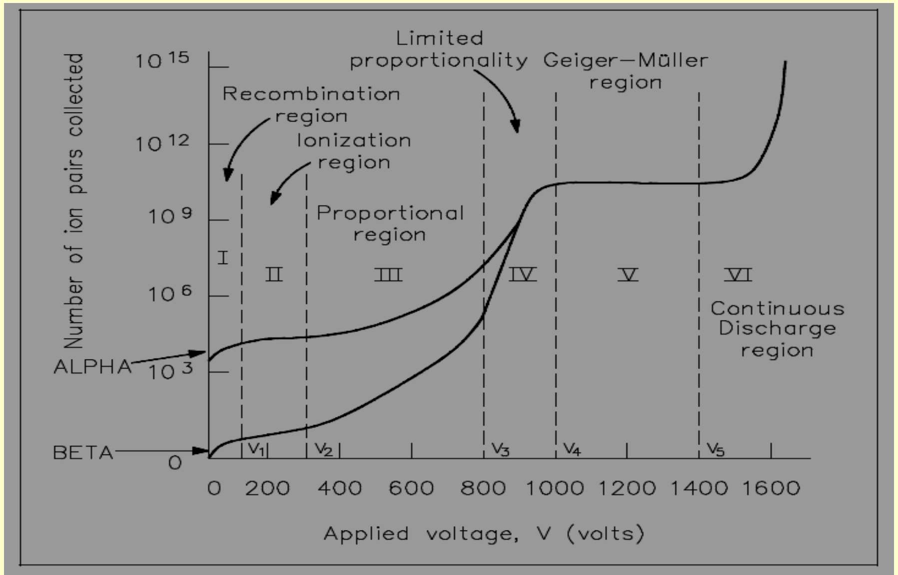


Figure 6 Ion Pairs Collected -vs- Applied Voltage

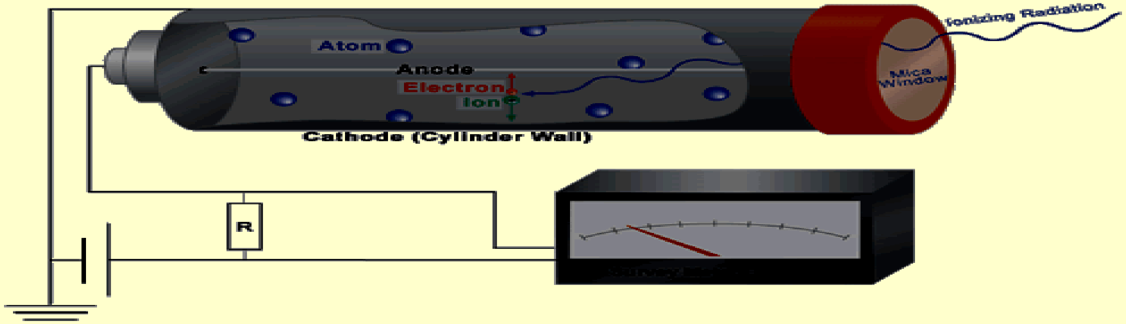
- **all** electron-ion pairs are collected
- **gas amplification ($A \sim 10^3 - 10^4$) is proportional to the applied voltage**

Proportional Detector

- When radiation enters a proportional counter, the detector gas, at the point of incident radiation, becomes ionized.

- The detector voltage is set so that the electrons cause secondary ionizations as they accelerate toward the electrode.

- The electrons produced from the secondary ionizations cause additional ionizations.



- This multiplication of electrons is called gas amplification.

- Varying the detector voltage within the proportional region increases or decreases the gas amplification factor.

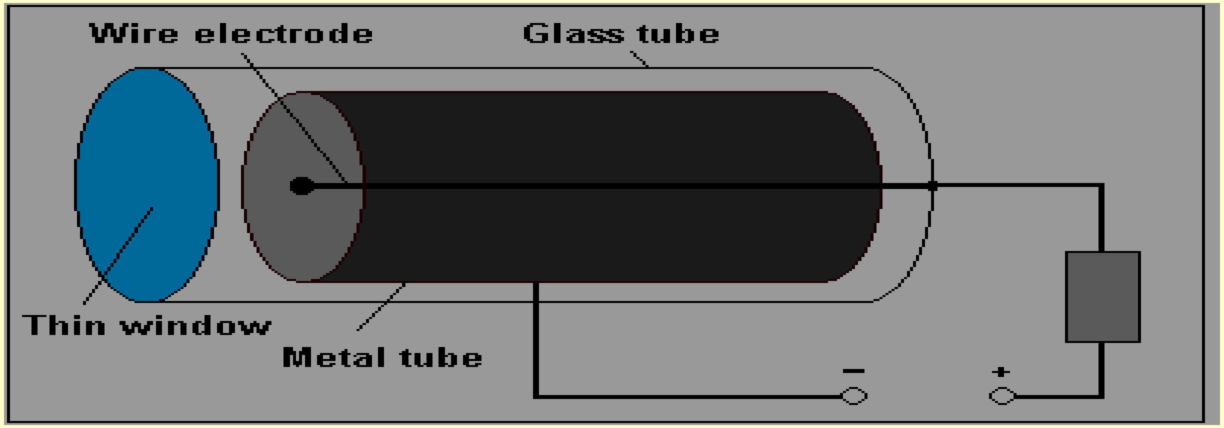
- A quenching gas is added to give up electrons to the chamber gas so that inaccuracies are NOT introduced due to ionizations caused by the positive ion.

↳Proportional Detector Properties

◙ identification of the any type of particle (α, β, γ) and its energy

◙ gas: helium, argon, (α, β, γ) or boron triflouride (neutrons)

◙ free electrons are produced by secondary ionization, photoelectric interactions, and bombardment of the cathode surface by positive ions



◙ detection of low energy particles (< 10 keV) is possible due to internal amplification

◙ quenching gas (methan) => limited lifetime => gas flow counters

Limited Proportional Region

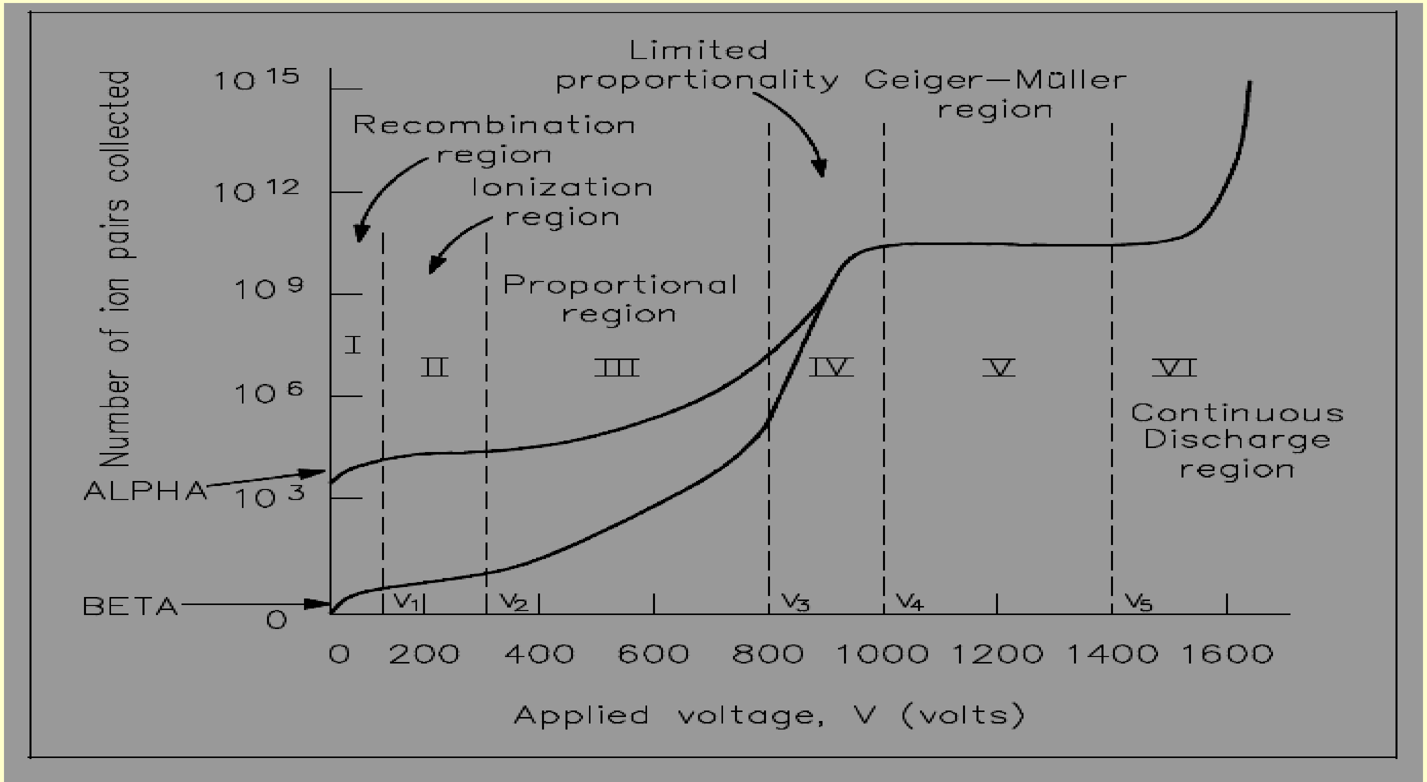


Figure 6 Ion Pairs Collected -vs- Applied Voltage

- **additional processes occur leading to increased ionization**
- **positive ions remain near their point of origin, further avalanches are impossible**
- **no counters operate in this region**

Geiger-Muller Region

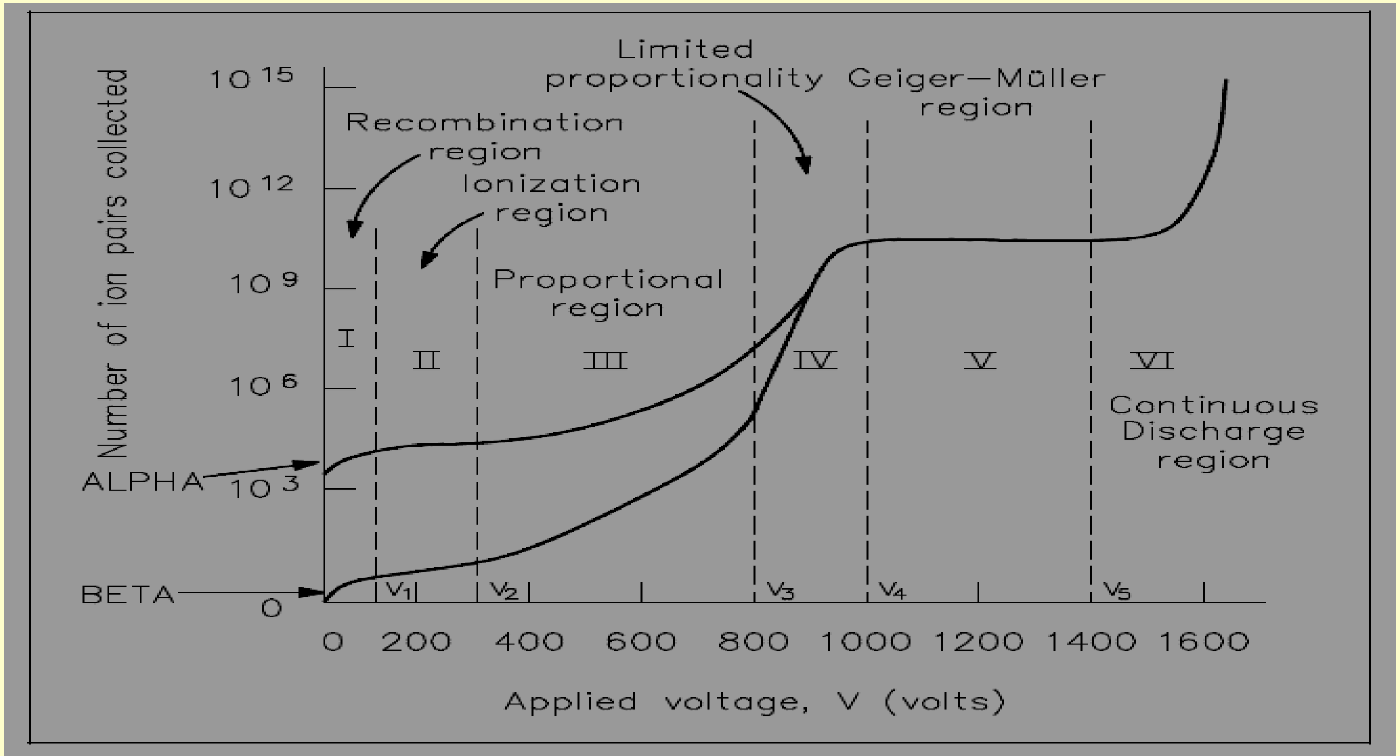


Figure 6 Ion Pairs Collected -vs- Applied Voltage

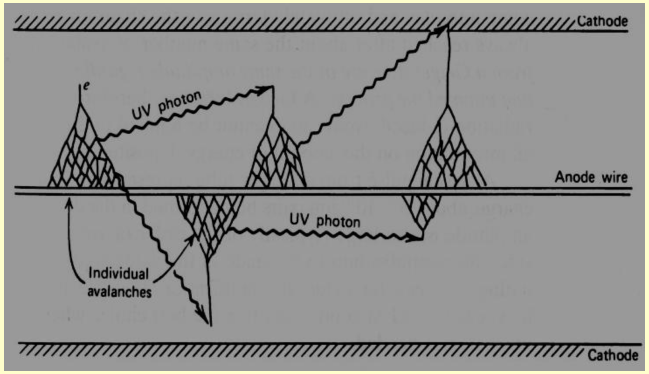
- **electron-ion pair production is independent on the type of incident radiation**

- **electric field strength so high that the discharge continues to spread until amplification cannot occur, due to a dens positive ion sheath surrounding the anode**

Geiger-Muller Detector

- The voltage of a Geiger-Muller (G-M) detector is set so that any incident radiation produces the same number of electrons.

- As long as voltage remains in the G-M region, electron production is independent of operating voltage and the initial number of electrons produced by the incident radiation.



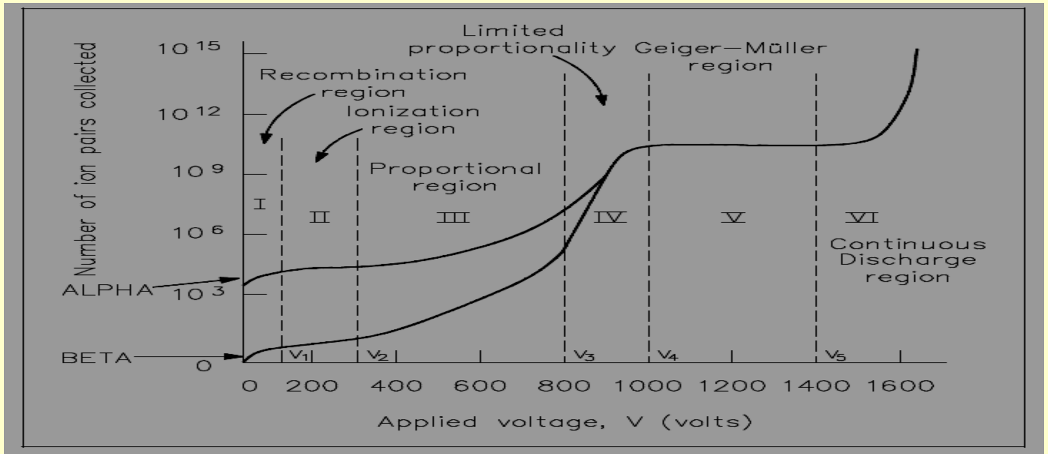


Figure 6 Ion Pairs Collected -vs- Applied Voltage

- The operation voltage causes a large number of ionizations to occur near the central electrode as the electrons approach.

- The large number of positive ions form a positive ion sheath which prevents additional electrons from reaching the electrode.

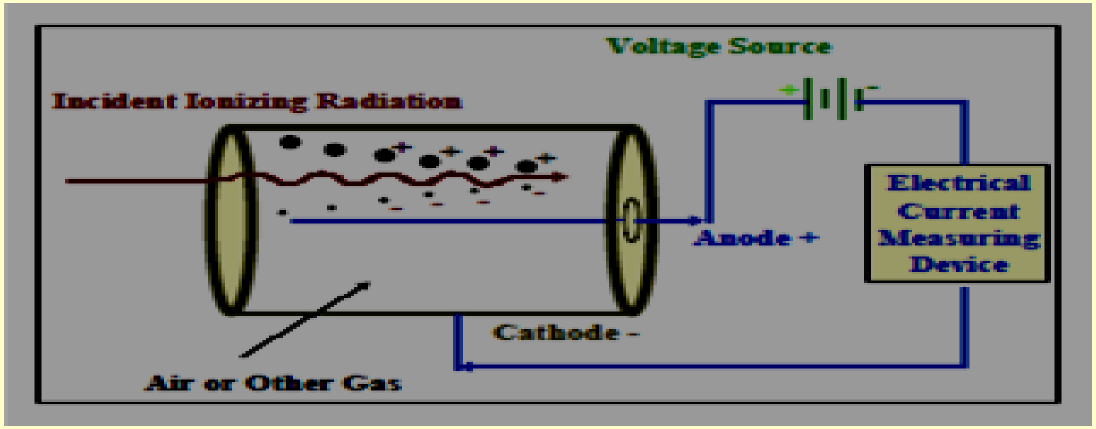
- A quenching gas is used in order to prevent a secondary pulse due to ionization by the positive ions.

Geiger-Muller Properties

- identification of the type of radiation is impossible

- information only about the number of particles

- positive ion sheath around the central wire => reduced field strength -> quenching gas



- finite lifetime due to degradation of the filled-in gas

- use limited to low counting rates due to large dead time

- sensitive detectors -> portable instrumentation, simple counting circuit, ability to detect low level radiation

Continuous Discharge Region

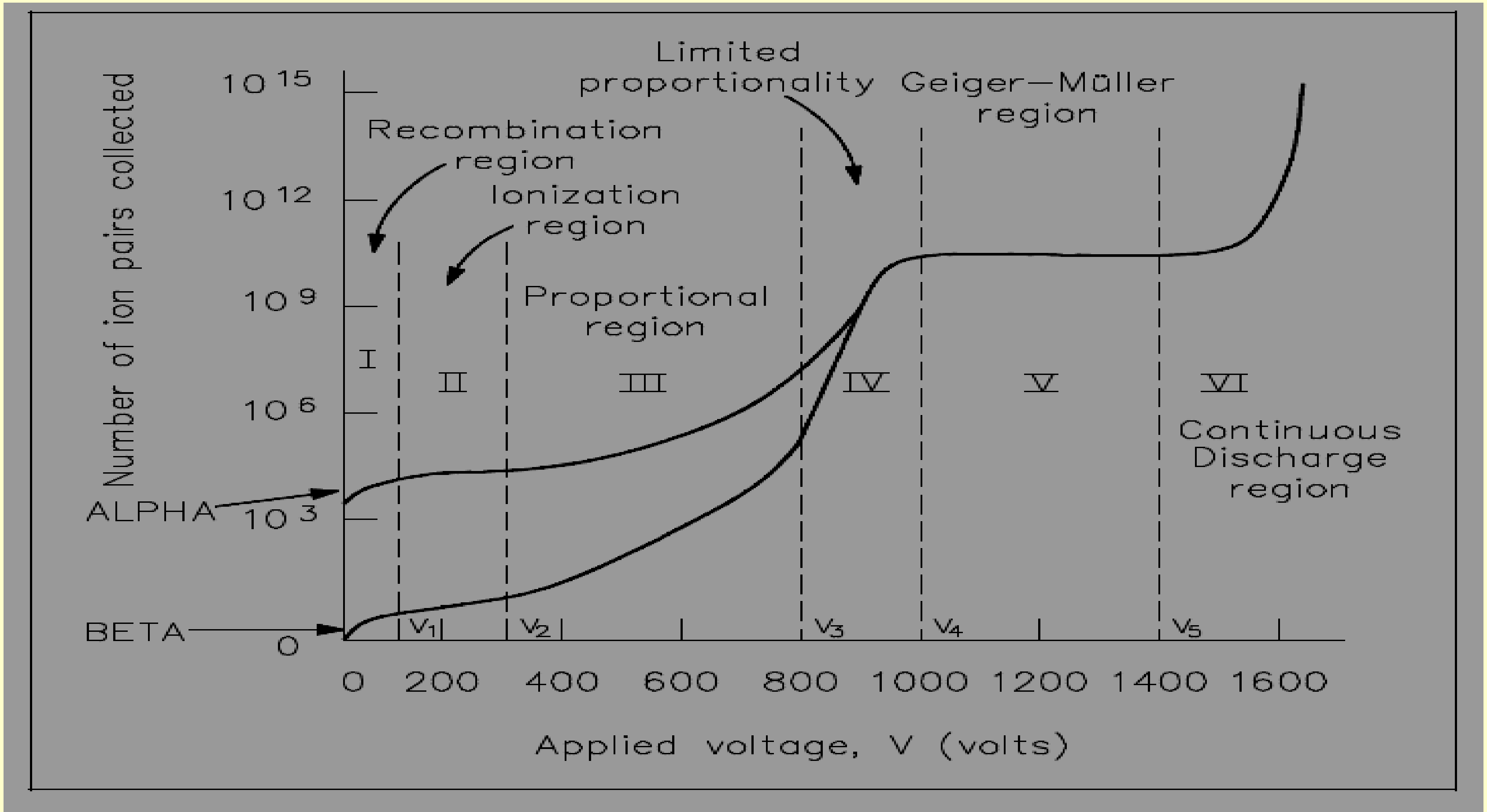
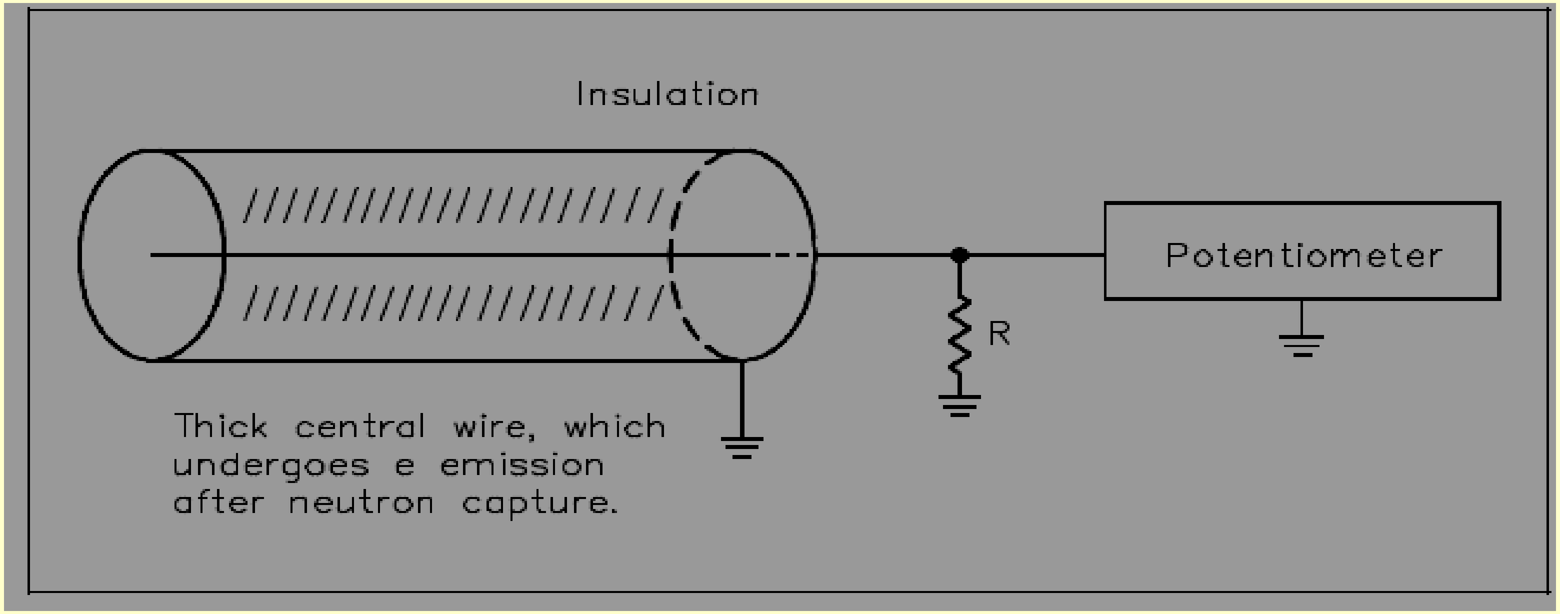


Figure 6 Ion Pairs Collected -vs- Applied Voltage

- the applied voltage is so **high** that, **once ionization takes place**, there is a **continuous discharge**

Miscellaneous Detectors

1- Self-Powered Neutron Detector



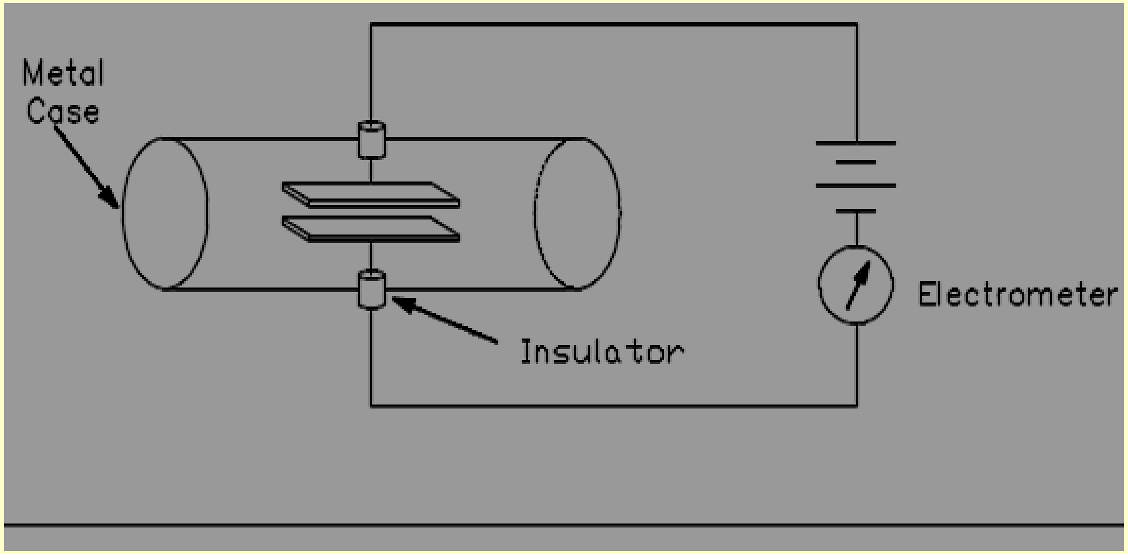
The central wire, made of a neutron-absorbing material, absorbs a neutron and undergoes beta decay.

As more beta decays occur, the remaining atoms cause the wire to become more positively charged.

The voltage potential set up causes a current flow in a resistor, which is measured by either a millivoltmeter or electrometer.

Miscellaneous Detectors

2- Wide Range Fission Chamber



- **Neutrons interact with the U^{235} coated chamber causing fission of the U^{235}.**

- **A highly positive charged fission fragment interacts with the detector gas and causes ionizations.**

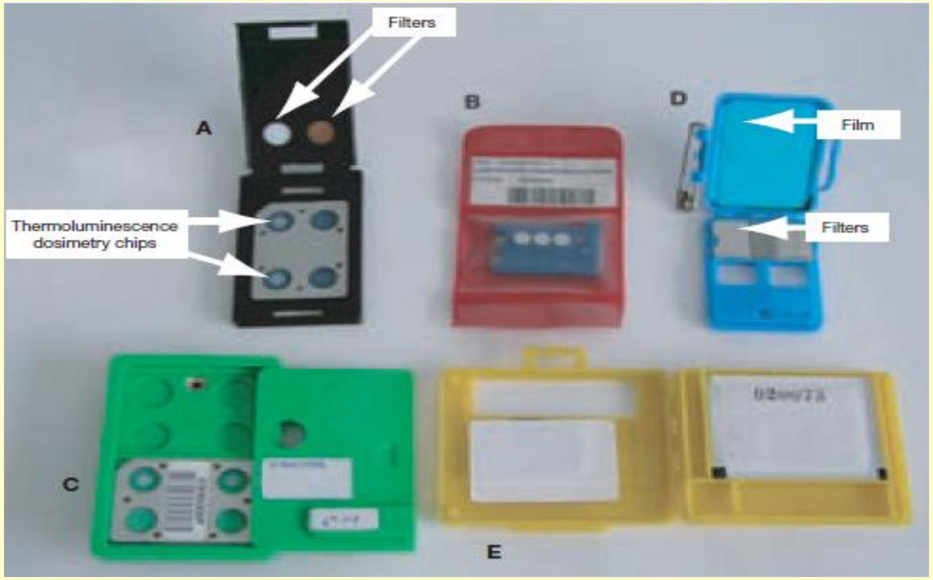
- **The electrons produced are collected as pulses on the electrode.**

↳ Miscellaneous Detectors

3- Activation Foils and Flux Wires

↳ The **wire** is inserted directly into the core and becomes **activated** by the **neutron flux**.

↳ When the **is reached, the wire is removed** from the core and co desired activation time counted.



4- Photographic Film

↳ Detects total radiation dose by **darkening; film darkness determines** overall exposure.

↳ Fast neutron exposure determined by **counting individual proton recoil tracks**.